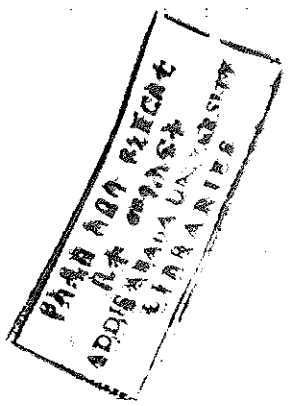
ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

ETHNOBOTANICAL STUDY OF EDIBLE OIL CROPS AS A COMPANION OF *SORGHUM BICOLOR* L. MOENCH AND BIOCHEMICAL GENETIC ANALYSIS OF *IN SITU* AND *EX SITU* CONSERVED *GUIZOTIA ABYSSINICA* (L.f.) CASS.GERMPLASM FROM NORTH SHEWA AND SOUTH WELO

By

MULATU GELETA

ADDIS ABABA, ETHIOPIA, JUNE, 2001



ETHNOBOTANICAL STUDY OF EDIBLE OIL CROPS AS A COMPANION OF *SORGHUM BICOLOR* L. MOENCH AND BIOCHEMICAL GENETIC ANALYSIS OF *IN SITU* AND *EX SITU* CONSERVED *GUIZOTIA ABYSSINICA* (L.f.) CASS.GERMPLASM FROM NORTH SHEWA AND SOUTH WELO

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES, ADDIS ABABA UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIEMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN BIOLOGY (*APPLIED GENETICS*)

BY

MULATU GELETA

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Ethnobotanical study of edible oil crops as a companion of *Sorghum bicolor* L. Moench and biochemical genetic analysis of *in situ* and *ex situ* conserved *Guizotia abyssinica* Cass. germplasm from north Shewa and south Welo

By

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A Thesis Presented to the School of Graduate Studies of the Addis Ababa University in Partial Fulfillment of the Degree of Masters of Science in *Biology*

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DEDICATION

TO THE MEMORY OF MY SISTER W\ZO YESHI-BIREHAN GELETA

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Abstract

South Welo and north Shewa are the center for the diversity of Sorghum bicolor. Sorghum is cultivated in close association with oil crops mainly because of their combined uses in the cultural feeding system of local people. The presence of multipurpose sorghum landraces in the area have played a significant role for oil crop species diversity and their in situ conservation, as each oil crop has its own unique domain in its combined use with sorghum. The companionship of sorghum and oil crops is multidimensional, which includes multiple cropping practices at the field level, multi-component food values. Their companionship is deep rooted to the level of society's traditional beliefs and sacrifices and cultural life. Guizotia abyssinica and Sesamum indicum are the most important oil crops of the area with strongest companionship with sorghum both at the field level and home level. The stronger the companionship of a given oil crop with sorghum at home level, the stronger the companionship at field level too. This result is based upon (i) the interviews with local farmers (both males and females) with heterogeneous age groups, and (ii) field survey together with local farmers and the in situ team in order to collect data on the cropping patterns and degree of companionship of sorghum and edible oil crops. Different Agromorphological traits from six oil crops were analyzed for the purpose of obtaining the level of variability among populations of each oil crop and correlation between traits. Analysis of variance (ANOVA) and correlation analysis were conducted for quantitative traits, while Shannon's diversity index analysis was conducted for qualitative traits, to see the potential genetic diversity of these oil crops. Capsule length, number of capsules per plant and number of seeds per capsule are important for high yield in Sesamum indicum. Number of branches per plant and number of heads per plant are the main traits that determine yield in Guizotia abyssinica. In Carthamus tinctorius, number of capitulum per plant, which is a primary trait to determine yield, did not show significant correlation with other traits studied. In Brassica carinata, number of primary branches per plant, plant height and number of seeds per capsule show significant positive correlation between themselves implying that these traits might be important agronomic traits for high yield. Shannon diversity estimates revealed that more than 74% of the total variation is due to within populations or area, for all species analyzed.

Multilocus enzyme electrophoresis (MLEE) was used to assess genetic variability in twenty in situ conserved populations and twenty ex situ conserved populations of Guizotia abyssinca. MLEE analysis at four enzyme loci scores 19 alleles. All 19 alleles were recorded in both in situ and ex situ populations. Dendrograms constructed based on Nei's genetic distance values show that there is no clear differentiation between the two groups. All four loci were polymorphic and characterized by significant heterozygote deficiency ($P<0.001$) and significant deviation from Hardy-weinberg equilibrium ($P<0.001$). Mean Shannon's diversity index between the two groups is too small which explained only 0.8% of the total variation. Both group show almost the same level of diversity as revealed by both F-statistics and Shannon's diversity index. Marked differentiation between populations (Fst= 0.313 and 0.237, for in situ and ex situ populations, respectively) was observed. Averaged overall populations there was a mean number of alleles per locus (A) of 2.125 and 2.265, a mean percentage polymorphic loci (P) of 72.50 and 76.25, and a mean observed heterozygosity (H_o) of 0.249 and 0.265 for in situ and ex situ conserved populations, respectively, which suggest a rather higher level of genetic diversity in ex situ populations than that of in situ populations. The values of these variables, deferred considerably between populations, which might be because of small sample size used and few number of loci studied. Although there are some biases introduced due to small sample size used and few number of loci studied, the parameters calculated have shown large level of genetic variability, which is the result of hundreds of generations of continuous in situ conservation that have been reshaped by farmers' selection criteria.

1. INTRODUCTION

1.1. GENETIC DIVERSITY AND ITS MAINTENANCE

Genetic diversity is the genetic variation present in a population or species, which has resulted through adaptation to new environments, mutation and continuous selection. Modern crops with stored genetic diversity are the result of thousands of years of evolutionary processes. Selection that leads to crop evolution is of two types: natural and artificial. Artificial selection is human activity that involves reshaping of domesticated crops to meet human needs and wants. These evolutionary processes must continue in order for agriculture to be an evolving system and remain viable (Brush, 2000). Both farmers and scientists have relied on genetic diversity present in crop plants for their selection criteria. Therefore, genetic diversity within and between plant species is an obvious necessity for the growth and improvement of crops in diverse environments (Bekele, 1985; Worede *et al.*, 2000).

Genetic diversity is important both to individual farmers, communities and to agriculture in general. Individual farmers value diversity within and between their crops because of heterogeneous soils and production conditions, risk factors, market demand, consumption, and uses of different products from an individual crop species (Bellon, 1996).

According to Bekele (1985), genetic diversity helps to overcome stresses imposed by pests, parasites, pathogens and environment on crop varieties that range from a reduced productivity to extinction in evolutionary prospective. Genetic diversity also allows farmers to exploit the full range of varied micro-environment differing in characteristics such as soil, water,

temperature, altitude, slopes and fertility (Worede *et al.*, 2000). The need for diversity at both the farm and regional levels has resulted in a vast store of genetic diversity in crops, a store passed down from earlier generations and maintained for the future (Brush, 2000). Hawkes (1983) explained that in regions where a crop's evolution has the longest record, where the crop was originally domesticated, and where its diversity is greatest, the local store of genetic diversity in farming communities is also a store of genetic resources for that crop, an invaluable resource for farmers, scientists, and consumers elsewhere.

However, there is high rate of erosion and irreversible loss of genetic variability and structure of landrace populations of various plant species because of several factors including, diffusion of modern crop varieties and commercial farming into every agricultural system, changes and development in agriculture or land use, destruction of habitats and ecosystems, and drought (Bekele, 1983a; Worede *et al.*, 2000). Such changes result in the replacement of diverse, local populations of crops with a handful of modern varieties that have been bred for broad adaptation, resistance to disease and other risk factors, high yields and so on (Bekele, 1983a; Brush, 2000).

Ethiopia is a major world center of genetic diversity for many important domesticated crop plant species such as sorghum, barley, tef, noog, chickpea, and coffee, largely represented in the country by landraces and wild types that are uniquely adapted, genetically diverse forms of these crops (e.g. Worede *et al.*, 2000). Ethiopian farmers have been creating, maintaining, and promoting crop genetic diversity through: (i) the farming practices allow intercross of cultivated crops with their wild or weedy relatives growing in the same field or in nearby fields, (ii) the frequent intercropping or mixed cropping practices allow genetic introgression within these mixes, which results in rapid diversification among the included species. For example, such mixing has been reported between Ethiopian mustard (*Brassica carinata*) and

black mustard (*Brassica nigra*) (Worede, 1987). More specifically, South Welo is rich in crop landrace diversity, particularly *Sorghum bicolor* (L.) Moench (Geberekidan and Kebede, 1979; Teshome, 1996). The farmers of south Welo have maintained their crop landraces for thousands of years by using their traditional preservation methods and farming practices (Teshome, 1996).

1.2. COMPLEMENTARY CONSERVATION STRATEGIES

The importance of crop genetic resources and threats to them has led to the creation of conservation programs to preserve crop resources for future generations. These conservation programs could be generally categorized as *ex situ* and *in situ* conservation (Bekele, 1985; Fourie, 1986; Brush, 2000). *Ex situ* conservation refers to maintenance of genetic resources in gene banks, botanical gardens, and agricultural research stations (Plucknett *et al.*, 1987; cited in Brush, 2000). *Ex situ* conservation may be further sub-divided into several specific techniques: (i) seed storage, (ii) in vitro storage, (iii) Pollen storage, (iv) field gene bank, and (v) botanical gardens (Maxted *et al.* 1997). *In situ* conservation refers to maintenance of genetic resources on-farm or in natural habitats within the community of which they form a part, allowing the natural processes of evolution to take place (Asfaw, 2000; Brown, 2000). This generates the establishment of new variation, which provide different patterns of gene survival that affects the potential for future evolution and adaptability under changing environment (Bekele, 1985).

The goal of *in situ* conservation is to encourage farmers to continue to select and manage local crop populations, which maintains diverse alleles and genotypes but also evolutionary processes such as, gene flow between different populations and local knowledge systems such as folk taxonomies and information about selection for heterogeneous environments (Brush, 2000). Maintenance of species and genetic diversity in farmers' fields is crucial to sustainable agriculture, especially for resource-poor farmers under low-input conditions in marginal lands (Worede *et al.*, 2000).

Landrace evaluation and enhancement programs will certainly be needed to promote more expensive utilization of germplasm resources that are already adapted to drought-prone regions of Ethiopia (Worede *et al.*, 2000). In Ethiopia, maintaining landraces is probably best achieved through farm or community based conservation programs.

1.3. IMPORTANCE OF ETHNOBOTANICAL STUDY IN MAINTAINING GENETIC DIVERSITY

Ethnobotanical studies are important for *in situ* conservation strategies. In other words, indigenous knowledge, about crop diversity at different age and in both sexes, generated from ethnobotanical studies is important for future on-farm conservation and diversification of that crop. Conversely, on-farm conservation maintains indigenous knowledge about the farming system and agricultural practices that retain diversity and knowledge about direct use of that diversity (Brown, 2000). Ethiopia could be taken as a typical example for this because, traditional farming represents centuries of accumulated experience and skills of peasants who often sustained yields under adverse farming conditions using available resources (Worede *et al.*, 2000).

According to Asfaw (2000), different sources of indigenous knowledge (traditional sayings, poems, beliefs, value systems and ethos) that refer to attributes such as, growing habits, seed quality, yield etc, help to enhance the conservation and use values of local landraces of crops. When a certain crop species has been cultivated by a society for long time it is not only utilized for consumption and drinks but usually it is also used for society's crucial practices including rituals, beliefs and sacrifices (Altieri and Merric, 1987: cited in Asfaw, 1990), which has its own significant role in maintaining genetic diversity of that species.

The value of a given plant species or its landraces in the lifestyle or identity of a particular social group may encourage its maintenance. Landraces may have specific valued traits that cannot be obtained from exotic sources, which valued them for specific local traditions including religious festivals, everyday meal and medicinal practices. Brush (1995) described that cultural preference plays a role for crop genetic diversity through continuous cultivation

of preferred landraces. Because of such significant importance, several researchers have conducted ethnobotanical studies on different plants to generate information for future conservation programs, for example, barely (Asfaw, 1990), fishtail palms (Everett, 1995) and wild edible fruits (Jin *et al.*, 1999).

1.4. IMPORTANCE OF AGROMORPHOLOGICAL STUDIES IN MAINTAINING CROP DIVERSITY

Researching the agromorphological characteristics of crop varieties is significantly important for on-farm conservation research because: (i) farmers use many of the agromorphological characters of plants to identify and select their crop varieties (Jarvis, 1999 & Jarvis *et al.*, 2000), (i) farmers' use these traits to select varieties with high yield and good resistance to pest, disease and drought (e.g. Patil and Sherif, 1996). In other words, farmers' seed selection decisions are based on the range of agromorphological characteristics that their crop exhibit, indicating that agromorphological traits link farmer behavior and genetic diversity. Because of such importance in maintaining genetic diversity, several researches have been conducted on agromorphological characters and farmer perceptions, for example: Sorghum (Teshome *et al.*, 1997, 1999a&b), rice, barley, taro and sponge (Bajracharya *et al.*, 1999), rice, taro and bean (Tin, 1999).

1.5. IMPORTANCE OF BIOCHEMICAL MARKERS IN STUDYING GENETIC DIVERSITY

Studying genetic diversity and divergence requires assessment of a number of marker diversity (e.g. Allozymes, RFLPS, RAPDs and AFLPs) and variation in adaptation (Bekele, 1985; Brown, 2000). These quantitative estimates of genetic structure are prerequisites for genetic conservation strategy and to further split the gene diversity centers (Bekele, 1983a).

As one of quantitative estimates of genetic diversity, isozyme analysis have been used to quantify genetic diversity and determine population structure of various crop species, for example: barley (Bekele, 1983a&b, Linde-Laursen *et al.*, 1987), tetraploid wheat (Tsegaye *et al.*, 1994,1996a&b), *Gliricidia sepium* (Chamberlain *et al.*, 1996). Analysis of isozyme markers are advantageous, because the markers are co-dominant (Leberge, 1996) and allow identification of genotypes which are important in the study of genetic diversity. Isozyme expressions are known to be independent of the environment and hence useful tools to measure genetic variation (Yndgaard and Iloskuldsson, 1985; cited in Tsegaye *et al.*, 1994).

1.6. SORGHUM AND OIL CROPS

Sorghum is one of the leading cereals in the world and ranks fourth following wheat, rice and maize (Purseglove, 1972). It is the second in importance as a crop of subsistence in Africa south of the Sahara (Dendy, 1995; cited in Teshome, 1996). Various researches have been conducted on sorghum in Ethiopia. For example: Gebrekidan (1981), Kebede (1986), Ayana and Bekele (1999), Teshome (1996), Teshome *et al.* (1997, 1999a&b) of which the last two are specifically conducted at different areas of north Shewa and south Welo.

However, the question about the sorghum companion crops of these areas was not addressed in detail. Hence, this research project aimed to study edible oil crops as companion crops of sorghum (*Sorghum bicolor* (L.) Moench) in north Shewa and south Welo.

Studies have shown that there is significant variation among populations of Ethiopian *Guizotia abyssinica* (C.f.) Cass. from different regions of the country, for example, in seed oil

content (Seegeler, 1983; Riley and Belayneh, 1989; Dagne and Johnson, 1997; Dutta *et al.*,1994; Alemaw and Sharma, 1996) and fatty acid composition (Dutta *et al.*, 1994), Morphological and agronomic traits (e.g. Alemaw and Belayneh, 1989; Alemaw and Sharma, 1996).

On the other hand, Aga (1999) reported that there was no variation observed in chloroplast DNA restriction fragments generated by BamHI, EcoRI, HindIII and Sau3AI restriction enzymes, not only among noog accessions but also between noog and other closely related species of the genus *Guizotia*.

The present study was, hence, undertaken with the objectives outlined in section 2 below.

2. OBJECTIVES

2.1. GENERAL OBJECTIVES

1. To investigate the biophysical associations of sorghum/tef and oil crops in the field and their companionship at the household level in meeting the dietary and economic needs of farming communities
2. To characterize and describe some agromorphological traits of edible oil crops on farm
3. To investigate and compare genetic diversity of *Guizotia abyssinica* (C. F.) Cass. conserved *in situ* and *ex situ*
4. To generate information on farmers' selection criteria in maintaining different oil crops and their landraces to meet variable social, cultural, economic and ecological needs

2.2. SPECIFIC OBJECTIVES

1. To describe the farming systems and agricultural practices associated with oil crops as companion crops of sorghum
2. To show the role of sorghum diversity and farmers' selection criteria for sorghum landraces for on-farm conservation of oil crops
3. To determine the degree at which each edible oil crop is associated with sorghum at field level (intercropping and border cropping) and at home level (for various use values)
4. To compare the frequency of each oil crop with sorghum (late and early maturing) and tef
5. To see agromorphological variation of some edible oil crops conserved *in situ* under diverse environmental conditions between populations and areas
6. To estimate and compare some genetic variability measures and genetic distance values within and between populations of *in situ* and *ex situ* conserved *Guizotia abyssinica* (noog), and to generate information for future research on noog at biochemical and molecular level
7. To compile the specific features of each oil crop from collection of folklore referring to them, their use values, cultural values, and to show the role of these uses for on-farm conservation

3. LITERATURE REVIEW

3.1. CROP GENETIC DIVERSITY

Ethiopia is one of the centers in the world where crop plant diversity is strikingly high and is a center where some crop species were domesticated (Vavilov, 1951). As stated by Teshome

(1996), Ethiopia is also a region where the traditional farming systems have co-evolved with the diverse landraces over millennia. This great genetic diversity of crops is the base for sustainable way of increasing productivity, through exploiting the natural resources found in the farm (Altieri and Merrick, 1987).

These variable and diverse crop plant populations of the traditional farming systems, which are known as landraces or folk varieties have been used as the basis for modern commercial agriculture and the development of the high yielding varieties (HYVs) (Frankil, 1974; cited in Teshome, 1996). Plant breeders depend on landraces maintained by or collected from the traditional farmers for the genetic material required to develop new high yield varieties with the needed resistance to diseases and pests (Teshome, 1996). However, giving priority to HYVs is disadvantageous because of their genetic uniformity, which makes them vulnerable to the host of environmental constraints, including diseases and pests (Brown, 1983). Thus, conserving crop landraces is crucial to maintain traditional knowledge of cropping patterns and management practices and the ecological rationale behind them (Chambers, 1983; cited in Teshome, 1996).

3.2. COMPARISON OF *IN SITU* AND *EX SITU* CONSERVATION STRATEGIES

On-farm conservation, as a major part of *in situ* conservation strategy, has been defined as "the continuous cultivation of local varieties and management of a diverse set of populations by farmers in the agroecosystems where a crop has evolved." (Bellon *et al.*, 1997; cited in Jarvis *et al.*, 2000). On-farm conservation is perhaps the most recent technique for genetic conservation recognized by scientists, but has obviously been practiced by traditional farmers for millennia (Maxted *et al.*, 1997).

Traditionally *in situ* conservation has been used for the conservation of forests, wild species and areas valued for their wildlife or ecosystems, while *ex situ* conservation has been a predominant approach for conservation of plant genetic resources for food and agriculture (Brown, 2000). However, today *in situ* and *ex situ* methods are no longer perceived as exclusive alternatives to each other, rather, they are seen as complementary approaches (Brush, 2000). These conservation strategies have their own respective advantages and shortcomings.

On-farm conservation has several major benefits including preserving plant genetic resources, conserving the processes of evolution and adaptation, conservation of indigenous knowledge, and public and private benefits (Brown, 2000; Jarvis *et al.*, 2000).

On-farm conservation concerns entire agroecosystems, including immediately useful species, as well as their wild and weedy relatives that may be growing in nearby areas, which are used as sources of genes in the habitats where such diversity arose and continuous to grow (Brown, 2000; Jarvis *et al.*, 2000). Since *ex situ* conservation is designed to maintain genetic material in the state in which it was collected, to avoid loss or degradation, it is well suited to capture and store alleles and genotypes. However, it is not suited to the conservation of the other components of the agroecosystem, such as agroecological interrelationships and human factors (Brush, 2000).

On-farm conservation scheme allows cultivation of crops, in heterogeneous agroecosystems (Asfaw, 2000), which allows the maintenance of those components in living and ever changing agroecosystems (Brush, 2000). Unlike *ex situ* conservation, *in situ* conservation gives chance for the production of resistant varieties to pests and disease out breaks (e.g. Asfaw, 2000).

Ex situ conservation strategy is relatively easy to identify the genetic diversity as the material is usually fully documented for the use of plant breeders and other scientists, which is less likely in the case of *in situ* conservation (Jarvis *et al.*, 2000). *Ex situ* conservation is disadvantageous in that it removes genetic material from its natural environment thus halts the ongoing evolutionary processes, which help to make landraces unique and adaptable to changing environments. Furthermore, because *ex situ* conservation can be highly expensive, it affects the choice of which crops are collected for *ex situ* conservation, as only major crops or those of high economic value as determined by breeders and scientists are likely to receive attention (Jarvis *et al.*, 2000).

3.3. SORGHUM: ECONOMIC IMPORTANCE AND AGRONOMIC PRINCIPLES

Sorghum is one of the leading cereals in the world and ranks fourth following wheat, rice and maize (Purseglove, 1972). Sorghum is indigenous to Africa (grown in semiarid zones, which include the large belt spreading from Atlantic to Ethiopia and Somalia, bordering the Sahara desert in the north and the equatorial forest in the south and extending south wards through the drier regions of eastern and southern Africa (Dendy, 1995; cited in Teshome, 1996). It is the most important crop of rainfed agriculture in drought prone lowland areas of semiarid tropics including Ethiopia (Gebrekidan and Kebede, 1979). According to Vavilov (1951), Ethiopia is considered as a center of origin of sorghum.

Sorghum is grown as sources of food, feed and industrial row material. Sorghum grains are used for human consumption. It has high starch content, and hence, it is an energy providing food (Hulse, 1980). Sorghum provides one third of the cereal diet and is grown almost

entirely by the subsistence farmers and fermented bread made of sorghum is popular in Ethiopia, especially in areas where sorghum is cultivated as major crop (Chanteareau and Nicou, 1994;Teshome, 1996).

In Ethiopia, sorghum is cultivated under a wider range of environment, which incorporates lowlands, middle highlands, and highlands each of which constitutes one or two agroecosystems (Meganasa, 1982), and it is grown at altitudes from 400-3000 m in areas where annual rainfalls vary from 400-2000 mm (Teshome, 1996).

There are several sorghum landraces in Ethiopia. According to Teshome *et al.* (1997), landraces are variable plant populations adapted to local agroclimatic conditions, which are named, selected, and maintained by the traditional farmers to meet their social, economic cultural and ecological needs. They are the source of great genetic diversity because they are the results of natural and artificial selection in their centers of origin (Harlan, 1975; cited in Teshome, 1996).

3.4.MULTIPLE CROPPING SYSTEM

Multiple cropping refers to all cropping patterns where two or more crops are cultivated on a field in one growing season (Steiner, 1982). Steiner further explained that specific multiple cropping systems have developed over the centuries in different regions and they are closely adapted to the prevailing ecological and socio-economic conditions.

Intercropping is the cropping pattern in which more than one crop is planted in alternate rows or planted randomly without any specific spatial arrangements, which are sometimes specified as row intercropping and mixed intercropping, respectively (Steiner, 1982). In many literature sources, the term intercropping is used synonymously with mixed intercropping. According to Matsaers (1978), intercropping is the central part of traditional farming systems in most parts of tropical Africa.

Intercropped plants compete for limited growth factors or resources such as light, water and nutrients. Cropping systems have a direct influence on the performance of genotypes and cause considerable changes in the relative yields of genotypes. According to Steiner (1982), crop cultivation system of small farmers is associated to ideas of home consumption, some monetary income and protection against natural risks. They, therefore, preferred intercropping systems due to the fact it mainly reduces economic and environmental risks, and at the same time fulfill subsistence objectives. However, the distribution of crop varieties in the traditional farmers' locality is determined by environmental condition and farmers' objectives.

In Ethiopia, particularly in the study area of this work, farmers know which crops to grow in mixture and which to grow singly. For example, noog and tef are not commonly planted in mixture to avoid the shading effects of noog, which decreases tef yield. Thus, farmers prefer planting noog along the periphery of tef plots, to eliminate competition for light between the crops, meet their food requirements from tef and obtain cash from the sale of both crop species (Teshome, 1996).

3.5.OIL CROPS

3.5.1.GENERAL DESCRIPTION OF OIL CROPS

There are about 328 oil plant species in Ethiopia, of which 15 are cultivated (Demisssie *et al.*, 1992). Out of these cultivated species, some are economically very important. These include noog (*Guizotia abyssinica*), sesame (*Sesamum indicum*), linseed (*Linum usitatissimum*), sunflower (*Helianthus annuus*), safflower (*Carthamus tinctorius*), Ethiopian mustard (*Brassica carinata*), caster (*Ricinus communis*), groundnuts (*Arachis hypogaea*) and cotton (*Gossypium* spp.) (Alemaw and Alemayehu, 1992; Demissie *et al.*, 1992).

These oil crops are generally grouped into two broad categories, depending up on their major growing environment, as: (i) highland oil crops, and (ii) lowland oil crops. In Ethiopia, highland edible oil crops include noog, linseed, Ethiopian mustard, and rapeseed (*Brassica napus*) (Alemaw and Alemayehu 1997), while lowland oil crops include groundnut, safflower and sesame (e.g. Weyessa, 1987).

Oil seeds, in addition to their provision of basic dietary requirement of the majority of the population, they have high industrial uses including manufacture of soaps, paints, lubricants and fertilizer production (Seegeler, 1983). The residue from edible oilseeds is rich in protein and is generally used for agricultural purposes, either for stock feeding or as fertilizer (e.g. Belayneh *et al.*, 1981). However, when adequately refined it can be used as human food (Belayneh, 1991). Generally, oilseeds are unique in that they are a dual-purpose crop

providing large quantities of both oil and protein. Carbohydrate (cellulose, starch and sugars) is also the major component of oilseeds (Simpson, 1997).

In Ethiopia, oilseeds play an important role in the traditional nutrition; in which the seeds are usually consumed entire, which might be because most common Ethiopian dishes are cooked, rather than fried (Seegeler, 1983). Oilseeds are most commonly consumed through using them for preparing stew ("wot"), particularly on fasting days (Belayneh, 1991). Seegeler (1983) stated that mixtures of roasted oil seeds with spices are used by travelers as 'instant food', especially in Gonder.

As stated in Seegeler (1983), Ethiopian annual oil crops have the following attractive properties: (i) are well adapted to a wide range of environmental conditions and agricultural practices, because of their high variability, (ii) their oil can be consumed locally and can also be exported, and they have varied uses, thus extending demand, (iii) oil extraction is simple and (iv) oils and seeds can be stored easily for sometimes, even under warm conditions.

3.5.2. NOOG (*GUIZOTIA ABYSSINICA (L.F.)* CASS.)

3.5.2.1. Origin, Distribution and Ecology

Noog (*Guizotia abyssinica*) (L.f.) Cass. (2n=20) belongs to the genus *Guizotia* Cass. in the family Compositae, tribe Heliantheae and subtribe Coreopsidinae (Baagøe, 1974; Dagne, 1994). According to Baagøe (1974) and Hiremath and Murthy (1988), *G. abyssinica* was derived from *G.scabra* ssp *schimperi*, which is supported by available phytogeographical, cytological and morphological evidence (Demissie *et al.* 1992; Dagne, 1994; Murthy, 1996).

This species might have evolved from *G. scabra* through disruptive selection (Doggett, 1987; Demissie *et al.*, 1992).

G. abyssinica is the only domesticated species of the genus and it has been under cultivation in Ethiopia, India and some other east African countries (Baagøe, 1974; Dagne, 1994). The European name for *G. abyssinica* is Niger, which was probably derived from the Ethiopian vernacular name of noog (Baagøe, 1974). Since the suggested progenitor, *G. scabra* ssp *schimperi*, is native to Ethiopian highlands, it is believed that this crop was domesticated in Ethiopia (Harlon 1971; cited in Dagne, 1994). Hiremath and Murthy (1988) suggested that noog reached India as an already domesticated crop through trade routes. The suggestion is more likely, because of absence of wild *Guizotia* from India, which makes independent domestication unlikely (Dagne, 1994).

The optimal range of altitudes for noog cultivation is from 1500 to 2500 m (Alemaw and Sharma, 1996), within temperature range of 15-19^{O}C and rainfall range of 600-1000 mm during the growing season (IAR, 1989), which indicates that noog has wider distribution in mid and high altitudes. It does not show a clear preference for a particular soil types, and it does better than other crops even on heavy and poorly drained clay soils (Alemaw and Alemayehu, 1997).

The yield of noog is very low as compared to other oil crops and/or cereals, regardless of management practices used (Teklewold and Alemaw, 1993). Since the production of seed depends on successful flowering, fruiting and the number of seeds reaching maturity, its low productivity is associated with several factors. Such as: (i) self-incompatiblity nature of the

crop (Rilay and Belayneh, 1989; Nemomissa *et al.*, 1999), (ii) significant interactions of genotypes and environment (GxE) for several traits that determine yield (Kumar *et al.*, 1998), (iii) uneven ripening of heads on individual plants and in whole fields, which can result in a considerable preharvest loss (Seegeler, 1983) and (iv) presence of several insect pests [(e.g. leaf minor (*Sphaeroderma guizotiae* selman)] (Abdi *et al.*, 1993; cited in Haile, 1993) and diseases [e.g. Noog blight (*Alternaria* sp.)] (Alemaw and Teklewold, 1992).

Self-incompatibility is one of the major problems, which are associated with the process of screening the germplasm of *G. abyssinica* for improvement (Sinha *et al.* 1993b; Nemomissa *et al.*, 1999). This is because self-incompatibility does not allow production of desired traits through inbreeding or free intercrosses.

3.5.2.2. Agricultural Practices Associated with Noog

Guizotia abyssinica is the top ranking oil crop in Ethiopia, which accounts for 56-67% of the total area and production volume of oil crops in the country (Alemayehu and Ashagrie 1992). Intercropping of noog with other crops has various effects. Paikary *et al.* (1993) reported that noog crop in general suppresses the growth and yield of other intercrops to varied extent, which might be due to early growth vigor of noog in comparison to other crops. Unlike this report, various researchers have shown that noog intercropping can boost production and income per unit area of the farmer. For example, several researchers (e.g. Paikary *et al.*, 1993: Tiwari *et al.*, 1994; Pannose *et al.*, 1996) concluded that intercropping of noog with soybeans give the highest monetary return as compared to other noog based cropping system.

In row intercropping practices, the ratio at which each crop species is cultivated has significant effect on overall net return. For example, according to Tiwari *et al.* (1994), the 3:1 sorghum: noog intercropping ratio gave the highest sorghum equivalent yield and net returns as compared to 6:2 and 10:2 row ratios of intercropping. In Ethiopian traditional agriculture, the seed is always broadcast, however, according to Seegeler (1983), planting on rows, 25-40 cm apart, as done in India, is generally advantageous.

3.5.2.3. Variability in Noog and Heritability of Agromorphological Traits

Many researchers reported the absence of distinct local varieties of noog with better agronomic traits. For example, Tekelewold and Alemaw (1993) reported that it was difficult to improve noog seed yield as desired. According to them, the reason for this difficulty is that the variability for desirable plant traits such as high seed yielding, resistance to lodging and shattering are lacking. However, some research results have shown that desirable characters for high yielding are not lacking. For example, Nemomissa *et al.* (1998) identified agronomically interesting genotypes with high seed yield when they concluded that, large head (LH) genotypes had more seeds/head, hence high yield. Furthermore, variability that leads to the production of desired traits could be enhanced through induced mutation (e.g. Tekelewold and Alemaw, 1993).

Studies have shown that different traits have different levels of variability in noog. For example, days to maturity, plant height, heads per plant, number of branches per plant and 1000-achene weight were the main characters contributing to variability in noog (Biswas *et al.* 1993; Patel *et al.* 1993). There are some differences on different reports made by several

researchers on major traits that contribute to seed yield, which might be due to genetic variability among noog populations from different areas or countries. However, several researchers (e.g. Goyal and Sudhirkumer, 1993; Mishra *et al.*, 1993; Mathur and Gupta, 1995; Pradhan *et al.*, 1995; Borole and Patil, 1997) have reported that number of seeds/capitulum, number of branches/plant, and number of capitula/plant are the main traits that determine yield. In Ethiopia, though some improved varieties are introduced at different times they have no significant effect on productivity of noog (Alemaw and Sharma, 1996).

3.5.2.4. Uses of Noog

Noog is used for various purposes. The seeds yield a yellow, edible, semi-drying oil with little odor and a pleasant nutty taste (Purseglove, 1968). It provides about 50-60% of the edible oil produced in Ethiopia. Noog oil is mainly used for cooking purposes. Traditionally, the oil is prepared from slightly roasted and pounded or ground seeds; however, this traditional processing results in a very low oil yield (Seegeler, 1983). The press cake produced as a byproduct of both traditional and commercial oil extraction is rich in protein and is used as animal feed or manure.

Noog oil is also used in birth control and, cooked with spices, in the treatment of syphilis (Beleyneh, 1991). According to Seegeler (1983), noog sprouts being mixed with garlic and 'Tej' is recommended to cure cough. Refined oil is used for preparation of soaps, paints, illuminant and lubricant and for cleaning machinery (Vaughan, 1970; cited in Dagne, 1994). The high linoleic acid (70%) of significance in preventing arteriosclerosis in humans (Vaughan, 1970; cited in Abebe, 1978).

In addition to its use for oil extraction, noog seeds are prepared in different forms for consumption in Ethiopia. Crushed noog seed is used to prepare fasting 'wot' being mixed with pulses. Special food called "litlit" is prepared from slightly roasted and ground noog seeds after being mixed with salt. According to Seegeler (1983), this is sometimes given to young boys with big appetite, to keep them from eating too much. Slightly roasted seeds boiled in water are drunk during fasting season. Roasted noog seeds are pounded and eaten with bread, injera or "Kolo" (roasted grains of Sorghum, barley or wheat). In some cases, this roasted and pounded noog is traditionally used to cure diarrhea, syphilis and other diseases (Seegeler, 1983: Belayneh, 1991). In Ethiopia, noog is also cultivated for market to get cash and support low-income families (e.g. Alemayehu and Ashagrie, 1992). Noog may be planted as a protective border along a field of a crop more favored by animals, because, fresh plant is not eaten by cattle (Baldrati 1950; cited in Seegeler, 1983).

3.5.3. SESAME (*SESAMUM INDICUM* L.)

3.5.3.1. Origin, Distribution and Ecology

Sesame (*Sesamum indicum* L.) belongs to the genus *Sesamum* L. (x=8,13), which in turn belongs to family Pedaliaceae (Purseglove, 1968). It is one of the oldest oilseeds known. It has been in use since several thousands of years BC, in Middle East, Europe and Africa (Seegeler, 1983). As further described by Seegeler, because of its too early domestication it is impossible to indicate where and when domestication took place and thus where the plant originally came from. Morphological, biochemical and physiological studies have shown that the primary center of sesame diversity is in Africa (Hiltbrandet 1932; cited in Seegeler 1983), which is also supported by Pursoglove (1968). According to Pursoglove (1968), sesame was

first taken into cultivation in Africa and then it was taken at a very early date to India, where a secondary center of diversity developed. Ethiopia is generally accepted as the center of origin/diversity of sesame. Sesame is the major oil seed crop of the world (Weiss, 1971), of which India and China are the major producers (Sharma and Reddy, 1983; cited in Srivinasulu and Narayanasamy, 1993). In Africa, Sudan is the largest producer, which is followed by Ethiopia (Seegeler, 1983).

In Ethiopia, it is mostly grown in lowlands of northern Ethiopia particularly in Settit Humera and Metema, mainly for export markets (Weldemariam and Wakijira, 1985). It also grows in Fincha, Ababo, Dedessa, Pawe and the irrigated areas of the Awash Valley, Gode (Alemaw and Alemayehu, 1992), some areas in Welo, Tigray and around banks of Baro River (Westphal, 1975).

Sesame is a crop of the hot dry tropics and is usually grown as rainfed crop. It grows well at altitudes of 500-1500 m with a temperature of 23 °C to 28 °C, and it requires a low ranging rainfall of 500 to 700 mm with fair distribution during growing period (Demissie *et al.*, 1992). However, information from the germplasm collection by the IBCR indicated that the altitudinal range could extend up to 1900 m.

3.5.3.2. Agricultural Practices Associated with Sesame

Sesame is broadcasted or drilled in rows, when grown in pure stand (Purseglove, 1968). According to Weiss (1971) and Day (2000), this crop is difficult to mechanize and there is frequently a major loss of seed from shattering. An optimum time for harvesting appeared when one-third to two-thirds of the plant leaves, branches and capsules turned yellow (Weiss, 1971; Woldemariam *et al.*, 1993), to reduce seed loss due to shattering. In Ethiopia, there has been great loss of yield during harvesting (Woldermariam, 1993), which is mainly because of dehiscent nature of the crop due to the absence of cell layers over the median vascular bundles (Day, 2000).

Intercropping of sesame with other crops is a common practice in major sesame growing countries. Such agricultural practices might have importance in reducing risks associated to diseases and insect pests. For example, Ahuja *et al.* (1999) reported that intercropping of sesame with pearl millet reduced populations of beetles that attack sesame as compared to with sole sesame crop. Several researchers indicated that intercropping sesame with most crops gave higher net returns as compared to sole cropping (e.g. Sarma *et al.*, 1997).

3.5.3.3. Variability in sesame and heritability of characters

A large number of cultivars and races are known in sesame growing countries differing in their season of planting, time to maturity, degree of branching, number of flowers per leaf axil, which may be 1 or 3, number of locules in the capsule, which may be 4, 6 or 8 and in color of flower, capsule and seed (Purseglove, 1968; Xiao *et al.*, 1995). Unlike noog, sesame

is very largely self-pollinated, thus pure lines with desirable trait can be obtained easily (Xiao *et al.*, 1995).

Various research works have shown that characters such as number of capsules/plant, seed yield/plant, oil yield/plant, plant habit, flower color, capsule characteristics and so on have shown significant variation (e.g. Patil and Sheriff, 1996: Suburta and Maity, 1997; Bisht *et al.*, 1998). However, different agromorphological characters contribute different level of variation to the overall variation of this species. According to Patil and Sheriff (1996), most agromorphological traits have shown high heritability in sesame of which the majority of the traits show significant genetic variation. This makes sesame suitable for breeding purposes.

3.5.3.4. USES OF SESAME

Sesame is nutritionally important oilseed crop with high protein (Das and Chadhury, 1999). Sesame seeds contain 45-55% oil, 19-25% protein and 5% water. The oil is a high quality oil, odorless, semi-drying and not liable to become rancid, and used as a substitute for olive oil as cooking oil (Purseglove, 1968). The oil is also used for manufacturing margarine and compound cooking fats. Additionally, sesame oil can be used as a lubricant and illuminant (Purseglove, 1968). Similar to noog, its press cake is an excellent feed for livestock.

The fried seeds are eaten in soups and, mixed with sugar, and are a popular sweetner in Africa and Asia (Purseglove, 1968). The seeds, after removal of the seed coat, are often scattered on the tops of cakes, bread and pastry. Young leaves are used as a soap vegetable in South

Africa, and various parts of the plant are used in native medicines in Africa and Asia, while the stems are used as firewood (Purseglove, 1968).

3.5.4. LINSEED (*LINUM USITITATISSIMUM* L.)

3.5.4.1. Origin, Distribution and Ecology

Linseed (L. U. L., n=15) is the only economically important species of the family Linaceae (Teklewold and Alemaw, 1993). It belongs to genus *Linum*, which comprises about 200 species (Friis, 2000). Cultivated linseed is most probably originated in the Near East and it is certainly one of the first oil crops ever domesticated in the area, and it has been cultivated at some time or another in all parts of Europe, Africa and the Near East (Seegeler, 1983). Linseed is successfully grown in subtropical regions and tropical highlands, between about 0 and 50 ^{O} latitude, because of its tolerance to drought period (Bunting, 1951).

Linseed is thought to have been an early introduction from Asia to Ethiopia (Belayneh, 1991), where it makes its center of diversity (Belayneh, 1985). It is the second most important oil crop in Ethiopia, next to noog, and it is grown especially in the highlands primarily for oil production (Seegeler, 1983). According to Seegeler (1983) and Alemaw and Alemayehu (1992), Arsi with the adjoining areas in Bale and Harar, East Welega, East Gojam, the Semien Mountains, Tigray and South Welo are the most important linseed areas of Ethiopia. Linseed grows well at an altitudinal ranges from 2000 to 2800 m with temperature of 12 ^{O}C to 18 ^{O}C and rainfall of 450 to 500 mm in the growing season (Alemaw and Alemayehu, 1992).

3.5.4.2. Uses of Linseed

Linseed is cultivated for both its stem fibers and its seeds, because the fibers are durable and have great tensile strength (Heywood, 1993; Friis, 2000). Linseed oil can be used as both cooking and industrial oil, which includes manufacturing paints, exterior paints and industrial coatings (Teklewold and Alemaw, 1993). Roasted and pounded linseeds are important to prepare porridge, "wot" (being mixed with pulses) and a beverage called "Chilka" (being boiled in water and salt or honey added) (Seegeler, 1983).

3.5.5. ETHIOPIAN MUSTARD [*BRASSICA CARINATA* A. BRAUN]

3.5.5.1. Origin, Distribution and Ecology

Ethiopian mustard (*Brassica carinata* A. Braun) (n=17, BBCC) is believed to have originated in Ethiopia from the natural hybridization of *B. nigra* (n=8, BB) (Black mustard) and *B. oleracea* L. (Gurage or Wolayita Gomen, n=9, CC) (e.g. Alemaw and Alemayehu, 1992; Demissie *et al.*, 1992), followed by the chromosome doubling of the hybrid plant. *B. carinata* is indigenous to Ethiopia, and is mainly cultivated in Ethiopian highlands and North Kenya (Demissie *et al.*, 1992; Teklewold and Alemaw 1993). This crop is introduced and sometimes cultivated in large parts of tropical Africa, Asia and America. It is widely cultivated within altitudinal ranges of 1350-3000 m (Jonsell, 2000). In Ethiopia, it is well cultivated within altitudinal range of 1500 m to 2800 m (MOA, 1986; Alemaw and Alemayehu, 1992) with a rainfall amount of 600 to 900 mm and temperature range of 14^{O}C to 18^{O}C (Alemaw and Alemayehu, 1992; Demissie *et al.*, 1992). It grows well on an agricultural fields with good fertility and drainage (Alemaw and Alemayehu, 1992; Demisssie *et al.*, 1992). Precipitation is

not very critical and it can grow well in the presence of some humidity in the air (Seegeler, 1983).

3.5.5.2. Agricultural Practices of Ethiopian Mustard

In the past many centuries, Ethiopian mustard has been grown exclusively by small-scale farmers, usually around their homestead, occasionally intercropped with cereals, such as maize, sorghum and potatoes (Seegeler, 1983). It has been traditionally grown under different kinds of stress conditions and thus natural selection has eliminated genotypes which might respond to better agricultural management practices and hence resulted in eroding its genetic variability (Shah *et al.*, 1993).

Ethiopian mustard is cultivated primarily either for green vegetables or for seed. Ethiopian farmers have given clearly different attention for mustard cultivated for its green vegetables or seed (Baldrati 1950; cited in Seegeler, 1983). According to Seegeler (1983), the one cultivated for its green vegetable is usually carefully tended on small specialized plots, often near houses and sometimes with irrigation. On the other hand, the seed bearing mustard is mostly found in mixed stands.

3.5.5.3. Uses of Ethiopian Mustard

Ethiopian mustard is certainly one of the most important species of *Brassica* as it is particularly grown as vegetable, oil seed, condiments, and also for medicinal purposes (Seegeler, 1983). It is certainly one of the most important vegetables in Ethiopian traditional cooking, which is considered an emergency food or poor man's food. Mustard is eaten as

special stew called "Gomen wot", after being cooked and additional ingredients such as salt, oil and /or butter are added. It is also cooked fried with various ingredients in both Ethiopia and Europe to suite dishes. In Sidamo, the cooked leaves are usually served with "enset" (*Ensete ventricosum*) to enrich the food with protein, because it contains about four times protein as enset (Seegeler, 1983).

Mustard seeds are also used in tanning leather, lighting and soap manufacturing and varnishes (Belayneh, 1991). Crushed mustard seeds are used to grease new "mitad" (earthenware pan to bake injera) to give the finishing touch. *B.carinata* gives high oil yield as compared to other *Brassica* species, which reaches as high as 46% (Alemaw, 1986b, cited in Alemaw and Alemayehu, 1992). However, the oil has to be adequately refined before being used as edible oil because of its high eruic acid (Woldemariam and Wakjira, 1985; Belayneh, 1991).

3.5.6. SAFFLOWER (*CARTHAMUS TINCTORIUS* L.)

3.5.6.1. Origin, Distribution and Ecology

Safflower (*C. tinctorious* L.) is an oil crop that belongs to the Genus *Carthamus* L. (x=8,12), which comprises about 30 species distributed in Asia, Africa and the Mediterranean region (Purseglove, 1968). Safflower (2n=24) is the only economic species of the genus (Purseglove, 1968), which is only known in cultivation with primary centers in Afghanistan and Ethiopia. Modern researches point out that Palestinian area is a possible homeland of the species, while Ethiopia is considered to be a secondary center of variability of this species (Seegeler, 1983),

and probably the center of domestication (Demissie *et al.*, 1992). However, documentary or other evidence of its early history is not available (Seegeler, 1983).

In Ethiopia, the distribution of safflower is closely associated with the distribution of tef (*Eragrostis tef*) and barley, with which it is mostly intercropped (Seegeler, 1983). The crop is produced mostly in Harerge, Sidamo, Shewa, Arsi, Welo, Tigray and the adjoining areas of Gojam and Gonder (Demissie *et al.*, 1992; Woldemariam *et al.*, 1993).

Safflower is a crop of semi-arid areas with warm climates, which can be found cultivated between latitudes of 45^{O}N and 45^{O}S (Seegeler, 1983). At equatorial region, it is mostly cultivated at altitudes of 1600-2200 m and in Ethiopia, it is mostly cultivated at altitudes of 1700 to 2200 m (Weiss, 1971) with a rainfall of 600-1100 mm (Mesfin, 1970; cited in Seegeler, 1983). Safflower shows considerable resistance to drought and it does best on deep, fertile well-drained soils with neutral pH but cannot tolerate water logging (Purseglove, 1968). According to Seegeler (1983), although average temperature of 17-20 ^{O}C seem to be best for safflower, the plant is rather cold tolerant and can even withstand some degrees of frost in its early stage.

3.5.6.2. Agricultural Practices of Safflower

Safflower is usually planted as a winter crop, often in mixed cultivation with cereals or pulses (Purseglove, 1968). It may be broadcast or planted in rows. In Ethiopia, safflower is almost exclusively grown in mixed cultivation with small grains, especially with tef. The initial slow growth habit of safflower makes it extremely susceptible to weed competition after

emergence, and two to three weeding may be required before the crop can compete (Seegeler, 1983). For oil production the plants are harvested when fully ripe and the seed is threshed and winnowed (Purseglove, 1968). Harvesting safflower is relatively simple, because the plant does not lodge or shatter and relatively resistant to insect attack and bird damage (Seegeler, 1983).

3.5.6.3. Variation in Safflower

Safflower genotypes differed significantly in their yield-attributing characters (plant height, branches per plant and capsules per plant) (Purseglove, 1968; Ghorpade *et al.*, 1993). These characters are significantly higher in spineless over spiny genotypes, but the reverse were true in case of seeds/capsules and 100-seed weight (Purseglove, 1968). Spiny forms are considered better for oil and spineless forms for dye production (Purseglove, 1968). According to Seegeler (1983), Ethiopian farmers never distinguish cultivars between this crop. Variability of most morphological characters of Ethiopian safflower is, on the average, clearly less than that of safflower from the other part of the world (Wu and Jain 1977; cited in Seegeler (1983).

3.5.6.4. Uses of Safflower

Safflower is cultivated mainly for its seed, which is used as edible oil and as birdseed (Dajue and Mundel, 1996) and also for its brilliantly colored florets with the orange red-dye Carthamin extracted from them (Tiwari and Namido, 1993). The decorticated cake or meal has a high protein content and is used as a stock-feed, while undecorticated cake is used as manure (Tiwari and Namido, 1993). Traditionally, the crop is also grown for its medicinal value, especially in China (Dajue and Mundel, 1996). The seeds are edible usually being roasted first, while the tender shoots may be used as a potherb (Purseglove, 1968).

Safflower has various uses in Ethiopia. A pounded seed wrapped in cloth is used to grease the injera pan. Decorticated seed is pounded finely and made into a stimulating beverage or into a specially prepared fasting food, called "Suf Fitfit". According to Seegeler (1983), in some areas homemade oil is prepared by cooking cracked seeds with water followed by skimming of the floating oil.

3.5.7. SUNFLOWER (*HELIANTHUS ANNUUS L.*)

3.5.7.1. Origin, Distribution and Ecology

Helianthus annuus L. (2n=34) is an important oil-seed crop, which belongs to the genus *Helianthus* L. (x=17) in the family Asteraceae, which comprises over hundred species (Purseglove, 1968). The cultivated sunflower is *H. annuus* var. *macrocarpus* (DC.) Ckill, which is not known in a truly wild state (Purseglove, 1968). According to Velazhahan and Jeyarajan (1993), this crop become popular because of its high quality edible oil, short duration and drought resistance characters. In Ethiopia, sunflower is one of the major oil crops in Awasa region, Beles and Dedessa (Solomon, 1988; cited in Kefene and Dilbo, 1993).

It has adapted to altitudinal range of 1300-2400 m with a temperature range of 16 ^{O}C to 25 ^{O}C and rainfall from 500 to 750 mm during the growing season (Purseglove, 1968). Sunflower grows well in Ethiopia at altitudes below 2500 m, but it is more common below 2200 m (Seegeler, 2000).

3.5.7.2. Agricultural Practices of Sunflower

Sunflower is a recently introduced oilseed and is of minor importance to the subsistence and traditional farming system in Ethiopia (Demissie *et al.*, 1992). Sunflower is a suitable oil crop for intercropping with many cereal crops (e.g. Mondel *et al.*, 1998; Masood *et al.*, 1998). The crop is treated as windbreak or border protection or in association with other crops (MOA, 1986). Kefene and Gebremariam (1983) reported that there was a significant variation among Ethiopian cultivars for yield and yield attributes.

3.5.7.3. Uses of Sunflower

It is commonly grown as an ornamental garden-plant and also used as a good honey plant, which bees visit frequently (Purseglove, 1968). Purseglove (1968) further explained that the seed kernels are eaten raw, roasted or salted, and also used as a feed for livestock, poultry and cage birds. The oil is used in cooking and in the manufacture of margarine and compound cooking fats. Being a semi-drying oil, it is used in blends with linseed and other drying oils in paints and varnishes and also as a lubricant and for lighting purposes (Weiss, 1971).

4. MATERIALS AND METHODS

4.1. GENERAL DESCRIPTION OF THE STUDY AREA

According to the present political boundaries, the study area is part of Amhara National Regional State (ANRS), which includes north Shewa, south Welo and Oromia zones, and is found west of the great East African Rift Valley, which bisects Ethiopia (Fig. 1). It lies between 39^{O} 38.5' E and 40^{O} 1.1'E longitude and 90^{O}56.2' N and 11^{O} 22.2' N latitude. The altitude of the study area ranges from 1,200 to 2400 m above sea level (Teshome, 1996). The

study area is important sorghum growing regions of Ethiopia (Teshome *et al.*, 1997) and it is characterized by dominant mixed cropping practices, mainly in sorghum and tef fields. The local farmers play a major role in creating, maintaining and selecting landraces of various crops that satisfy their changing needs. This area is part of semi-arid regions of Ethiopia characterized by the conditions of intermittent drought that results from low and uncertain rainfall with characteristics high temperature. The study area includes six specific sites, namely: Shewa Robit, Merewa Adere, Laygnaw Ataye, Borkena drainage (Area between Harbu and Kombolcha), Bati and Haik.

Table 1: - Average annual and growing season rainfall, mean maximum and minimum temperature of some sites within the study area, in 1999 and 2000.

	Year		Areas		
			Kombolcha	Bati	Haik
Mean rain fall (mm)	Annual	1999	87.78	ID	92.96
		2000	106.63	101.4	123.97
	Growing season	1999	121.3	ND	127.85
		2000	145.83	139.45	170.3
Mean max T^{O} (^{O}C)	Annual	1999	26.78	ND	26.47
		2000	27.12	ND	ND++
	Growing season	1999	27.4	ID	26.87
		2000	27.2	ND	ND++
Mean min T^{O} (^{O}C)	Annual	1999	11.86	ID	11.19
		2000	12.04	ND	ND++
	Growing season	1999	12.45	ID	13.31
		2000	13.1	ND	ND++

ID= Incomplete data, ND=no data.
Source: - Ethiopian National Meteorological services Agency.

The growing season of the year 2000 (April to November) was characterized with better rainfall (Table 1). The average rainfall, mean, maximum temperature and mean minimum temperature of the growing season in which the study was conducted was 145.83 mm, 27.2 ^{O}C and 13.1 ^{O}C, respectively, at Kombolcha. At Bati and Haik, the mean rainfall of the growing season was 139.45 mm and 170.3 mm, respectively.

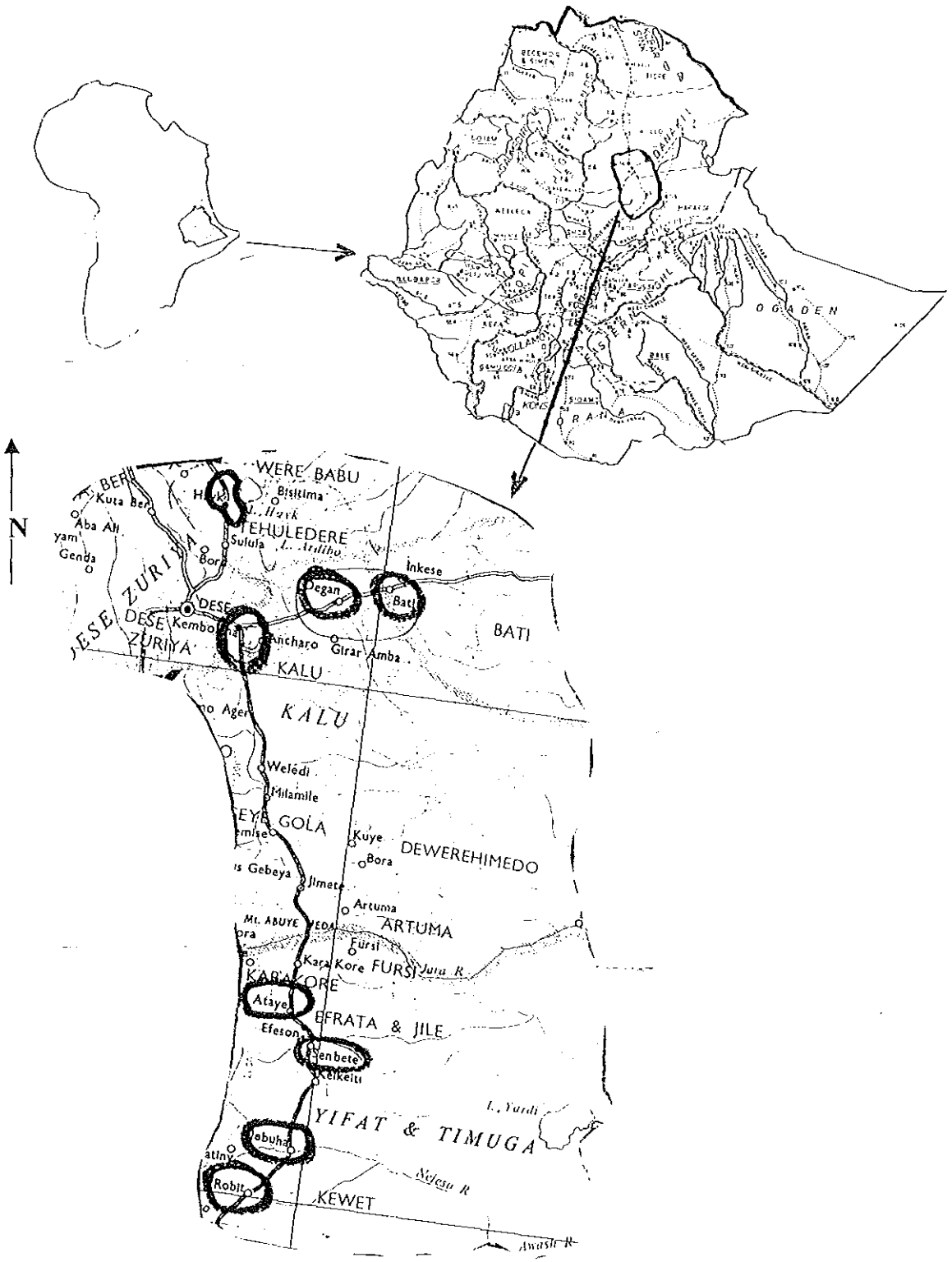

Figure 1: - The study area indicated on Map of Ethiopia (Ethiopian mapping authority)

4.2. SAMPLE COLLECTION

Samples of *Guizotia abyssinica* were collected from different sites within the study area (Appendix 2). The samples were collected directly from mature plants on-farm. Seed samples were collected from individual plants at five meters interval along transect lines, which were spaced five meters apart. To avoid the chance of using more than one seeds from the same plant for isozyme analysis, seed samples from each plant were kept in separate paper bags. For comparison purpose the samples were collected from the same site (area) as that of previously collected *ex situ* conserved samples selected for isozyme analysis.

4.3. ETHNOBOTANICAL STUDY

4.3.1. USE VALUES, FARMERS' SELECTION CRITERIA AND SEED CONSERVATION STRATEGIES OF EACH OIL CROP

Formal (see appendix 11) and informal interviews with both male and female farmers and other members of their families were undergone for six edible oil crops grown in the study areas. Data collection on the overall use values, farmers' selection criteria and seed source of each oil crop was undergone for five of the six study sites. The use values discussed were scored as farmers' traditional knowledge, if and only if at least 5 randomly selected informants of different age groups and sex know that use, and finally confirmed by key farmer informants with rich knowledge about use values of oil crops.

Data on companionship of edible oil crops and different landraces of sorghum at home level were collected by interviewing 30 farmers (20 males and 10 females) qualified for their knowledge about sorghum landraces and foods made of these sorghum landraces and different oil crops, Farmers were sampled randomly from Borkena drainage. Interviews were conducted with each individual after making sure that he/she could identify each landrace of sorghum. To be sure, whether they have sufficient knowledge they were asked to identify sorghum landraces from the standing crop and their identification was confirmed by farmer experts. Both male and female informants interviewed were only those that have cultivated at least some edible oil crop as companion of sorghum at field level.

4.3.2. OIL CROPS AS COMPANION CROPS OF SORGHUM AND TEF AT FIELD LEVEL

Data on association of oil crops and sorghum and/or tef were collected by surveying randomly selected sorghum and tef fields. Part of these data were collected during data collection on sorghum landraces and its frequency of occurrence per farmer's field, working with the *in situ* team.

The number of sorghum and tef fields studied in the six study areas were not equal. Each study area was represented by different number of fields, depending up on the abundance of sorghum and tef fields in the area. Based on this predetermined criteria, Bati, Borkena drainage, Haik, Laygnaw Ataye, Merewa Adare and Shewa Robit were represented by 114, 259, 61, 168, 20, and 109 sorghum fields, and 21, 53, 86, 31, 19 and 108 tef fields, respectively. In other words, 731 sorghum fields and 318 tef fields were surveyed in the

overall study area, to study the association between these oil crops and sorghum. Tef fields were surveyed in order to compare the agricultural practices of sorghum and tef.

4.3.3. THE DISTRIBUTION AND PROPORTION OF OIL CROPS AT FONTENINA

Data on distribution of each oil crop on fields of major crop at Fontenina were collected by surveying each farmers' fields from Borkena river to the top of the mountain ("Tele"), which are bounded with "Mermarsa river" at east and "Bamboua Wuha" at west. For data on the proportion and distribution of each oil crop within the field, quadrats of 4 m x 4 m (16 m^2) were measured at 5 locations per field, which were spaced equally over the field.

4.3. AGROMORPHOLOGICAL CHARACTERIZATION ON-FARM

Agromorphological traits that could be scored unambiguously were characterized for each oil crop on randomly selected farmers' fields using IBPGR (1981) scientific descriptors. However, traits characterized for sunflower and Ethiopian mustard are scored simply by selecting unambigious characters. For each oil crop, 5 fields per site were sampled, and each field was represented by 5 individual plants. To make these 5 individual plants a good representative of the population in the field, each field was measured diagonally, and that diagonal line was used as a transect line. Each plant at $1/5^{th}$ distance of the length of the diagonal line was characterized for both quantitative and qualitative characters. Characterization was conducted in the same manner for all samples of each species.

4.4. ISOZYME ANALYSIS

Twenty populations of *in situ* conserved and 20 populations of *ex situ* conserved *Guizotia abyssinica* from different sites of south Welo, north Shewa and Oromia zones of Ethiopia were used for isozyme analysis. *In situ* conserved samples were directly collected from farms, while *ex situ* conserved seeds were obtained from the Institute of Biodiversity Conservation and Research (IBCR). Each population was represented by five individuals and overall 200 individual seedlings were analyzed. However, for comparison purpose four randomly selected *in situ* conserved populations and four randomly selected *ex situ* conserved populations were reanalyzed by representing each population by 20 individuals. In the case of *in situ* conserved populations each seed was taken from a separate plant, while in the case of *ex situ* conserved populations, the seeds were selected randomly from the mixed individuals of the population. After a number of trials on age and tissue type preferable for better resolution, the four days old seedling shoots were used for analysis. Based on the availability of chemicals, the enzyme systems studied were Aspartate aminotransferase (AAT; EC 2.6.1.1.), a-Esterase (a-EST; EC 3.1.1.) and Leucine aminopeptidase (LAP; EC 3.4.11.1).

Isozyme analysis was conducted according to Harris (1994). The homogenates were prepared from fresh seedlings by grinding each shoot in pre-chilled round-bottomed microtitre dish with a fire polished glass rod, using two drops of general extraction buffer.

After extraction is completed, samples were immediately loaded to 13.3% starch gel. The starch gel was prepared by using 40 gm of electrophoresis grade starch and gel buffer

composed of 1.52 mM Tris and 5 mM citric acid. The electrode buffer used was prepared from 0.3 M boric acid (18.55 g/l distilled water) and 0.06 M sodium hydroxide, adjusted to pH 7.8. After electrophoresis was completed, the gel was sliced and stained using specific staining recipes for the three enzyme systems.

After 30 min incubation at 37^{O}C the staining solution was poured off and the developed bands were fixed using glycerol: water (1:1) ratio and stored at -4^{O}C overnight before band scoring. The isozyme data were scored the next morning.

4.5. DATA ANALYSES

M-STATC. software package (MSTATC. ,1991) was used to determine whether each oil crop has similar companionship with sorghum. Microsoft Excel was used for Z score test to see if each oil crop show significant differences in their cultivation as border crop or intercrop. Similarly, the same test was conducted to see the degree of companionship of oil crops with sorghum and tef.

The SPSS V. 7.5 (SPSS, 1998) Microsoft package was used for correlation analysis of the proportion of oil crops and sorghum plants per field, descriptive statistics, variance and correlation of quantitative agromorphological traits. Qualitative agromorphological traits were first analyzed using MINITAB computer program (MINITAB 98') and then the result was analyzed using Shannon's index $-\sum_{i=1}^{K} Pi \ln Pi$, where Pi is the phenotypic frequency and K is number of phenotypic classes recorded, to quantify diversity.

An assessment of isozyme phenotype polymorphism was made using the banding patterns. Phenotypic polymorphism, genetic distance, mean heterozygosity and mean deviation from Hardy-Weinberg expectation were determined using BIOSYS-1 (Nei, 1978; Swofford and Selander, 1981). In addition to the parameters offered by BIOSYS-1, Shannon's index of diversity was also employed as a means of quantifying genetic diversity, using the above formula, but *Pi* as frequency of genotypic classes. Nei genetic distances released by BIOSYS-1 were rearranged and transferred into MINITAB computer program (MINITAB 98') for constructing dendrograms.

5. RESULTS

5.1. ETHNOBOTANICAL STUDY

5.1.1. COMPANIONSHIP OF SORGHUM AND EDIBLE OIL CROPS IN THEIR USE VALUES

Different oil crops have been cultivated as companion crops of sorghum landraces for various combined use values including food values, medicinal values and cultural practices and traditional beliefs (Table 2), and most farmers cultivate their own oil crops from year to year (table 3).

5.1.1.1. Cultural Significance of Oil Crops

Oil crops feature in many cultural practices of the people of the study area. "Mewekel" or "Chele" is among the main practices where the importance of oil crops become visible, which is celebrated for wishing a relief for a sick person at home. The main food for this traditional ceremony is prepared from sorghum landraces, which pop or burst open upon roasting. The same food combination could be made by using roasted and dehulled barley or roasted chickpea, each mixed with roasted and finely pounded noog. Once the food is prepared the celebration takes place either at home or under the shade of big trees. During this ceremony, some amount of the prepared food is broadcasted in all directions to the maximum distance possible, before consumed by any one.

Another widely used cultural practice is "Agmas", which is commonly practiced during sorghum threshing. This process passes through the following steps: (1) Cress seeds, grasspea seeds and garlic are finely ground together between flat stones and dissolved by water in a container, (2) three ball shaped "Dimiso" are prepared from unleavened sorghum thin bread and roasted and pounded noog, and wrapped with broad leaves, and (3) three full panicles of sorghum are cut and made ready. After this, the prepared mixture in the container will be put beside the selected three spikes of sorghum on "Layeda" (traditional instrument used for winnowing the threshed sorghum), and the mixture is sprayed on to the spikes. Then, the three "dimiso" balls paired with the three sorghum panicles are put under the collected sorghum spikes on the winnowing field, which is ready to be threshed.

Once threshing is completed the three dimiso balls are broken into small pieces and eaten by the participants of the work, while the three spikes are mixed with the threshed sorghum and stored together. They do this because they believe that the yield will be higher and lasts long at home.

"Borenticha" is another cultural practice celebrated at the family level for wishing healthy life for the family and their domestic animals. It is a yearly celebration in May or June when black sheep is slaughtered, unleavened thin dehydrated bread ("kita") is prepared. Roasted and finely pounded noog made to ball shape is then put on the bread, and cut into small pieces. The next step is broadcasting the pieces and roasted grains of different cereals (including sorghum) in all directions. The rest of the food is shared among the participants of the ceremony and eaten. Most commonly the celebration takes place in the cattle yard ("Beret").

5.1.1.2. Medicinal Values of Oil Crops

Most oil crops have various medicinal values either specific to each species or common to most oil crops. Traditionally, noog is prepared in different forms to treat stomach problems. For example, it can be prepared by being roasted, pounded and mixed with water to be drunk, or to make into "Litlit" (a thick fluid made of slightly roasted and pounded noog grains and water) to be used instead of butter to eat with porridge. Unroasted noog grains are used as traditional medicine to treat wound when chewed and painted over the wound, because it facilitates healing of wound by preventing drying and cracking. Roasted and crushed noog seeds are boiled together with garlic and cattle bone marrow to make noog sprout. It is drunk after sugar is added and filtered, as a treatment for diseases associated with respiratory system. Noog might also be used to treat ear disease traditionally known as "ye joro nekersa" when mixed with other medicinal plants.

Sesame leaves from young plants are used to treat cattle's fatal disease locally known as "Antako". Farmers identify this disease by its diagnostic characteristics, which include swelling of the abdomen, lose of balance, falling to the ground and noisy sound produced by the animal, which may kill the animal within few hours. Cattle get the disease when they eat young sorghum plants inhabited by a dense population of very small insects. Sesame leaves are crushed, mixed with water and poured into the mouth and nose of the animal. The animal gets immediate relief after swallowing the preparation. Sesame leaves are also used traditionally as a detergent and insecticide. People of the area, especially children and youths use it to wash their hair and it makes their hair shiny, black, flexible and soft. Nowadays this

practice has declined because of availability of commercial soaps. However, still it is used in rural areas far away from towns. It has been used to destroy hair lice and in some cases to treat fungal infection, locally known as "Korokore".

Mothers who gave new birth are given special soup prepared from pounded linseed and honey as a treatment to reduce after birth bleeding. It is a common practice that pregnant mothers and mothers that gave new birth drink soup prepared from linseed to treat a disease state locally known as "Mich". In addition to linseed, safflower grains are also used to treat this disease, being boiled either unroasted or roasted and pounded to be drunk. Either unroasted or roasted linseed is boiled with sugar to be drunk as a treatment for stomach problems and dysentery. Linseed "Dimiso' might also be used to treat abdominal problems and dysentery. Similarly, unroasted safflower grains are eaten before breakfast to treat abdominal discomfort.

5.1.1.3. Use Values of Oil Crops in Food

The commonly known food types prepared from different landraces of sorghum, in which oil crops could be incorporated in different forms are "Dimiso", Boiled grains ("Nifro"), Bread, "Injera", Porridge, Roasted Grains ("Kolo"), and partially ground and boiled grains "Kinche" (Table 4-8). Different oil crops are preferably selected for different food types. In other words, Different sorghum landraces are combined with oil crops to be used as a food, and farmers give priority for specific landraces based on the type of food prepared (Fig. 3-5).

Table 2. Summary of farmers interview on local landraces of oil crops, their translation and main farmers selection criteria to cultivate oil crops in the area

Oil crops	Farmers' named varieties	Local name of landraces	Translation	Main selection criteria*
Noog	1	Tikur noog	Black seeded noog	Long shelflife of " kibanoog", dimiso, adaptation to marginal soils, oil quality, market demand, medicinal value, Disease/pest/bird resistance and protein rich press cake
Sesame	1	Key selit	Brown seeded sesame	Food values (mainly kibanoog, dimiso), high market demand, threshing ease, compatibility with sorghum at field level
Linseed	2	Dirib telba	Double seeded linseed	Food values (mainly for porridge) medicinal values, fast maturity, drought resistance, adaptation to low altitudes, high market demand in low lands
		Netela telba	Single seeded linseed	Food values (mainly for Porridge) medicinal values, high yield, high market demand for highlanders, better resistance to bird attack and diseases.
Sunflower	2	Nech ye ferenj suf	White seeded sunflower	Food values (mainly to mix with roasted grains)
		Tikur ye ferenj suf	Black seeded sunflower	Food values (mainly to mix with roasted grains)
Safflower	1	Ye Abesha suf	White seeded safflower	Adaptation to the area, food values, mainly for roasted grains, fitfit, market demand, dimiso
Ethiopian mustard	1	Gomenzer	Brown seeded Ethiopian mustard	Food values (mainly for leaves and young shoots consumption, fast maturity, "masesha", market value

* Criteria mentioned by more than 75% of farmers interviewed

Table 3. Summary of source of oil crops (percentage) on farm during the study season

Seed source	Shewa Robit	Laygnaw Ataye	Borkena drainage	Haik	Bati	Mean (percentage)
Farmer's own seed	73.33	75.00	80.00	81.25	94.40	80.8
Market	20.00	8.33	10.00	12.50	5.56	11.28
Exchange	6.67	16.67	10.00	6.25	0.00	7.92
n	15	12	30	16	18	

n (number of farmers interviewed)

Dimiso preparation is slightly variable. Commonly, dimiso is prepared from roasted and pounded noog or sesame mixed with thin bread of sorghum/tef. The mixture is ground together in the presence of sugar and made to ball shape, before consumption. It is also known as "ye rehab dula" ("king of hanger"), because one can stay for long period of time before feeling hungry after eating this food. It can also be prepared by spreading roasted and pounded noog/sesame over thin bread on the "Injera pan". After the bread is totally cooked, it is cut into pieces, ground and made into ball shape. In some areas, it is also known as "Chifko". Although it is not as common as noog and sesame, dimiso is also prepared from other oil crops such as linseed, safflower and sunflower. Sunflower is the third most important oil crop in preparation of dimiso (Fig. 2).

Noog and linseed are the most preferable oilseeds to prepare porridge with white seeded sorghum varieties (e.g. white gorad, white jamuye and white ismael), barely and wheat. Their seeds are roasted, finely pounded, made to thick fluid, and added to porridge to be consumed. Sometimes sesame is also used to prepare porridge

Boiled sorghum grains ("nifro") or roasted grains ("kolo") are mixed with roasted and pounded noog and sometimes sesame grains, which is deliciously consumed. Noog, sesame and safflower seeds can also be prepared in the form of thick fluid suitable to sip during eating bread and/or injera. A milky fluid prepared from safflower by boiling roasted and pounded seeds in which additional ingredients such as sugars are added is commonly used instead of milk during fasting period. Unroasted safflower seeds are sometimes pounded and mixed with water and left over night, from which a milky fluid is produced and it is consumed by sipping it with thin bread. A fasting food known as "ye suf fitfit" is commonly prepared

from safflower during fasting period especially among the followers of Orthodox Christian religion. Roasted and pounded noog and sesame seeds can be consumed with injera in the form of powder or dissolved in water. In some cases noog and sesame seeds are eaten raw in small amounts.

Traditionally, oil can be prepared from oilseeds at home. This homemade oil is locally known as "kibanoog". It is commonly prepared from slightly roasted and ground/pounded grains of noog and sesame. Sometimes, safflower, sunflower and linseed are also used. The powder is added to a pot, dissolved with appropriate amount of water, gently warmed and regularly shacken till the oil is released. The extracted oil is then skimmed off and used for cooking food. The use of kibanoog is like any commercially produced oil, including preparing "Wet"/stew, porridge and as a dressing for bread. Before modern oil mills were introduced to the area, using traditional oil mills was a common practice. These traditional oil mills use camel generated mechanical power, which is no longer a common activity in the study area, being seen during the field study only at a place about 9 km northwest of Bati.

Sesame and linseed may also be directly added to "Shiro wot' instead of oil, after being roasted, pounded and ground finely, especially by poor families who cannot afford to buy oil frequently. Sometimes roasted and pounded linseed is pasted with warm water and eaten with injera. Unroasted sesame seeds are sometimes consumed by mixing it with roasted fresh green sorghum landraces (e.g. "Goronjo" and "Barchuke"), locally called "enkuto". Sesame seeds are also used to prepare a food called "Firfir", in which roasted grains are finely pounded until oil starts to be released, which is then mixed with water and injera. Roasted safflower grains are commonly mixed with roasted grains of sorghum, wheat, barley and chickpea ("kolo"),

especially during coffee ceremony. This mixture of grains is commonly used as snack in the feeding system of local people.

Ethiopian mustard is mainly cultivated for food prepared from its leaves and young shoots. It is consumed either cooked or fried, especially the main rainy season. It is considered as a poor man's food, because of its fast growing nature. Farmers and other people depend on it till other crops (cereals) are harvested and threshed. Pounded seeds wrapped in cloth are commonly used to grease the "Mitad" (injera pan) to make it ready to bake injera and bread.

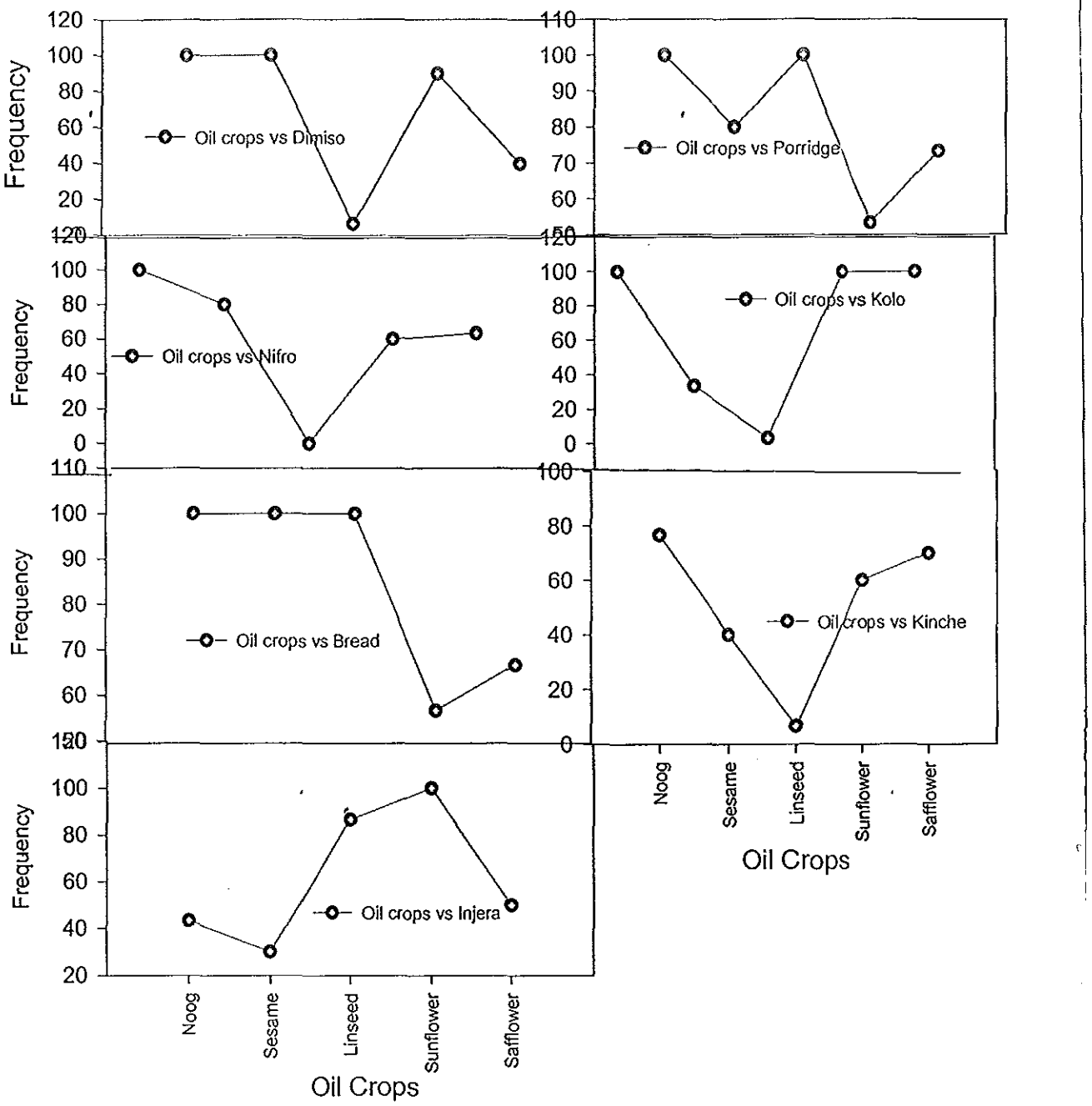

Figure 2. Frequency of positive respondents for combined use of sorghum landraces and each oil crop for different food values

Table 4. Farmers ranking of sorghum landraces as a food with noog

No	Sorghum landraces	Food types						
		Dimiso	Boiled grains (Nifro)	Bread	Injera	Porridge	Roasted Grains (Kolo)	Partially ground and boiled Grains (Kinche)
1	Abula Gorad	Average	Poor	Good	Poor	Average	Poor	Poor
2	Ahiyo	Average	Average	Poor	Average	Average	Average	Average
3	Amensi Tinkish	Poor	Poor	Poor	Poor	Poor	Good	Poor
4	Cherekit	Average	Poor	Average	Poor	Average	Average	Poor
5	Dikusie Tinkish	Poor	Poor	Poor	Poor	Poor	Average	Poor
6	Gorad	Excellent	Excellent	Excellent	Very Good	Excellent	Excellent	Excellent
7	Goronjo	Good	Very Good	Very Good	Good	Very Good	Good	Average
8	Isma'el	Average	Average	Average	Poor	Average	Poor	Poor
9	Jamuye	Good	Good	Average	Average	Excellent	Good	Poor
10	Jiru	Good	Average	Good	Average	Good	Good	Average
11	Mokake	Good	Excellent	Excellent	Good	Good	Very Good	Excellent
12	Subehan	Poor	Average	Poor	Poor	Average	Poor	Poor
13	Tengeley	Very Good	Excellent	Very Good	Good	Very Good	Good	Excellent
14	Tubah	Average	Poor	Average	Average	Poor	Poor	Poor
15	Wegere	Average	Poor	Average	Average	Average	Average	Poor
16	Wofaybelash	Poor	Average	Average	Average	Poor	Poor	Average
17	Zengada	Good	Average	Poor	Poor	Average	Good	Average

Excellent (15-30 positive respondents gave the first three Ranks), Very Good (10-14 positive respondents gave the first three Ranks), Good (5-9 positive respondents gave the first three Ranks), Average (1-4 positive respondents gave the first three Ranks), Poor (No positive respondentgave the first three Ranks)

Table 5. Farmers ranking of sorghum landraces as a food with sesame

No	Sorghum landraces	Food types						
		Dimiso	Boiled grains (Nifro)	Bread	Injera	Porridge	Roasted Grains (Kolo)	Partially ground and boiled Grains (Kinche)
1	Abula Gorad	Good	Good	Good	Poor	Poor	Poor	Poor
2	Ahiyo	Poor	Poor	Poor	Poor	Poor	Poor	Poor
3	Amelsi Tinkish	Poor	Poor	Poor	Poor	Poor	Average	Poor
4	Cherekit	Poor	Poor	Poor	Poor	Poor	Poor	Poor
5	Dikusie Tinkish	Poor	Poor	Poor	Poor	Poor	Poor	Poor
6	Gorad	Excellent	Very Good	Excellent	Very Good	Excellent	Good	Very Good
7	Goronjo	Average	Average	Good		Excellent	Poor	Good
8	Isma'el	Poor	Poor	Poor	Poor	Average	Average	Average
9	Jamuye	Excellent	Very Good	Good	Good	Good	Good	Good
10	Jiru	Average	Average	Poor	Poor	Average	Average	Poor
11	Mokake	Excellent	Excellent	Excellent	Poor	Average	Average	Poor
12	Subehan	Poor	Good	Poor	Poor	Poor	Poor	Poor
13	Tengeley	Average	Very Good	Very Good	Average	Good	Average	Good
14	Tubah	Good	Poor	Average	Average	Poor	Poor	Poor
15	Wegere	Poor	Poor	Poor	Poor	Poor	Average	Poor
16	Wofaybelash	Good	Poor	Poor	Poor	Poor	Poor	Poor
17	Zengada	Good	Average	Good	Average	Poor	Poor	Poor

For the details, refer to Table 4

Table 6. Farmers ranking of sorghum landraces as a food with linseed

No	Sorghum landraces	Food types						
		Dimiso	Boiled grains (Nifro)	Bread	Injera	Porridge	Roasted Grains (Kolo)	Partially ground and boiled Grains (Kinche)
1	Abula Gorad	Average	Poor	Poor	Poor	Poor	Poor	Poor
2	Ahiyo	Poor	Poor	Poor	Poor	Poor	Poor	Poor
3	Amelsi Tinkish	Poor	Poor	Poor	Poor	Poor	Poor	Poor
4	Cherekit	Poor	Poor	Poor	Poor	Poor	Poor	Poor
5	Dikusie Tinkish	Poor	Poor	Poor	Poor	Poor	Poor	Poor
6	Gorad	Average	Poor	Excellent	Excellent	Excellent	Average	Average
7	Goronjo	Poor	Poor	Excellent	Good	Very Good	Poor	Poor
8	Isma'el	Poor	Poor	Good	Poor	Average	Poor	Poor
9	Jamuye	Average	Poor	Good	Average	Very Good	Poor	Average
10	Jiru	Average	Poor	Average	Poor	Very Good	Poor	Average
11	Mokake	Poor	Poor	Very Good	Very Good	Excellent	Average	Poor
12	Subehan	Poor	Poor	Poor	Poor	Average	Poor	Poor
13	Tengeley	Average	Poor	Average	Excellent	Average	Very Good	Poor
14	Tubah	Poor	Poor	Average	Poor	Poor	Poor	Average
15	Wegere	Poor	Poor	Poor	Poor	Poor	Poor	Poor
16	Wofaybelash	Poor	Poor	Average	Average	Poor	Poor	Poor
17	Zengada	Poor	Poor	Good	Average	Average	Poor	Poor

For the details, refer to Table 4

Table 7. Farmers ranking of sorghum landraces as a food with sunflower

No	Sorghum landraces	Food types						
		Dimiso	Boiled grains (Nifro)	Bread	Injera	Porridge	Roasted Grains (Kolo)	Partially ground and boiled Grains (Kinche)
1	Abula Gorad	Poor	Poor	Good	Poor	Poor	Good	Poor
2	Ahiyo	Poor	Poor	Average		Poor		Poor
3	Amelsi Tinkish	Poor	Poor	Poor	Poor	Poor	Average	Poor
4	Cherekit	Good	Poor	Poor	Poor	Poor	Poor	Poor
5	Dikusie Tinkish	Poor	Poor	Poor	Poor	Poor	Poor	Poor
6	Gorad	Excellent	Good	Very Good	Excellent	Excellent	Excellent	Very Good
7	Goronjo	Average	Good	Poor	Good	Very Good	Poor	Good
8	Isma'el	Good	Average	Very Good	Poor	Average	Poor	Good
9	Jamuye	Good	Poor	Average	Excellent	Poor	Average	Good
10	Jiru	Average	Good	Poor	Average	Poor	Average	Good
11	Mokake	Average	Good	Poor	Good	Good	Poor	Good
12	Subehan	Poor	Poor	Good	Poor	Poor	Poor	Poor
13	Tengeley	Good	Very Good	Good	Very Good	Very Good	Excellent	Poor
14	Tubah	Good	Poor	Poor	Average	Poor	Poor	Average
15	Wegere	Good	Poor	Poor	Good	Poor	Poor	Poor
16	Wofaybelash	Poor	Poor	Poor	Poor	Poor	Poor	Poor
17	Zengada	Very Good	Poor	Poor	Very Good	Poor	Poor	Poor

For the details, refer to Table 4

Table 8: - Farmers ranking of sorghum landraces as a food with safflower

No	Sorghum landraces	Food types						
		Dimiso	Boiled grains (Nifro)	Bread	Injera	Porridge	Roasted Grains (Kolo)	Partially ground and boiled Grains (Kinche)
1	Abula Gorad	Poor	Poor	Poor	Poor	Poor	Poor	Poor
2	Ahiyo	Good	Good	Good	Good	Poor	Good	Poor
3	Amelsi Tinkish	Poor	Good	Poor	Poor	Poor	Good	Poor
4	Cherekit	Average	Poor	Poor	Very Good	Good	Poor	Poor
5	Dikusie Tinkish	Poor	Poor	Poor	Poor	Poor	Poor	Poor
6	Gorad	Good	Poor	Excellent	Good	Excellent	Excellent	Very Good
7	Goronjo	Poor	Poor	Good	Average	Good	Average	Good
8	Isma'el	Good	Good	Good	Poor	Poor	Average	Poor
9	Jamuye	Good	Good	Very Good	Poor	Excellent	Excellent	Good
10	Jiru	Poor	Poor	Poor	Good	Good	Very Good	Good
11	Mokake	Poor	Poor	Good	Poor	Poor	Excellent	Very Good
12	Subehan	Poor	Poor	Poor	Poor	Poor	Poor	Poor
13	Tengeley	Poor	Good	Poor	Average	Very Good	Poor	Good
14	Tubah	Poor	Very Good	Poor	Poor	Poor	Poor	Good
15	Wegere	Poor	Good	Poor	Good	Poor	Poor	Poor
16	Wofaybelash	Poor	Poor	Poor	Poor	Good	Poor	Poor
17	Zengada	Good	Average	Poor	Poor	Poor	Poor	Poor

For the details, refer to Table 4

5.1.1.4. Combined uses of Edible Oil Crops and Sorghum Landraces in Preparing Different Food Types

Most sorghum landraces are used to prepare dimiso commonly with noog and sesame; however, there are some landraces, which are preferable. The five top ranking sorghum landraces in dimiso preparation are "Gorad", "Mokake", "Jamuye", "Tengeley" and "Goronjo" (Fig. 3). According to farmers knowledge dimiso prepared from sorghum variety called "Zengada" is preferable in its quality to give strength (Fig. 4). Usually dimiso is consumed during threshing of major crops, mainly sorghum and tef. In some cases it is prepared during land preparation, harvesting and during the main rainy season to withstand the cool environmental conditions.

Noog has got the widest importance as a companion crop of sorghum in kolo. All farmers interviewed confirm its significant importance in preparing these food types (Fig. 2). A sorghum landrace known as "Gorad" is the only landrace that has got priority in preparation of all these food types. "Tengeley" and "Mokake" are also in the first group for preparing nifro in combination with noog. Mokake is considered best for bread with noog, while "Jamuye" has got priority for porridge with noog (Table 4).

Sesame is one of the most important oil crops in the preparation and consumption of Dimiso and bread (Fig. 2). Gorad and Mokake are the most preferable sorghum landraces with sesame (Table 5), both for dimiso and bread. Jamuye is also in the first category for preparing dimiso.

As one can see from Figure 2, linseed is one of the most widely used and most important oil crops in the preparation of bread and porridge. Here again Gorad is the only sorghum landrace that has got priority for both bread and porridge for the consumption with linseed. Goronjo"is considered best in its consumption with linseed as bread, while Mokake is one of the most suitable sorghum landrace for porridge together with linseed (Table 6).

Sunflower is cultivated in the area primarily for its food value in the consumption of injera and kolo (Fig. 2). Gorad has got priority here also for its food quality to be consumed with sunflower in the form of injera and kolo. Jamuye is one of the best sorghum landraces for injera when consumed with sunflower, while Tengeley is considered best for kolo when mixed with sunflower (Table 7). Safflower is primarily cultivated for its consumption in the form of kolo (Fig. 2). Gorad, Jamuye and Mokake are the most important sorghum landraces for kolo to be consumed mixed with safflower (Table 8).

Generally, 17 landraces of sorghum, which are about one third of major and distinct sorghum landraces cultivated in the area (Teshome, 1996) were got the first three ranks in the preparation of different food types, of which the main ones are those discussed above. Use values of sorghum and oil crops are expressed in different forms including poems, songs and sayings. These expressions are related to food and beverage quality, length of growing season, seed and flower color, planting and harvesting period, land preparation, threshing ease and so on of the crop (Appendix5).

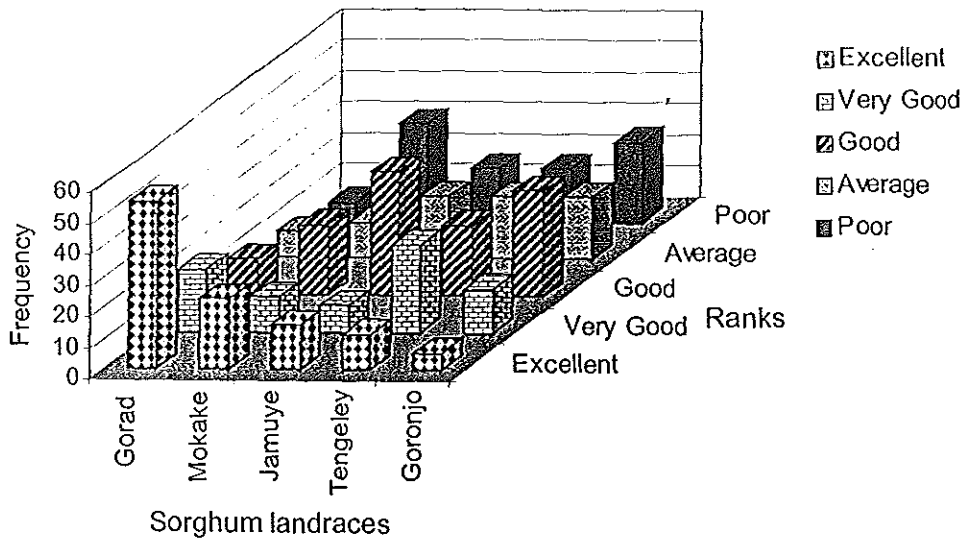

Figure 3: - Frequency of ranks given for top ranking sorghum landraces as a food with different oil crops.

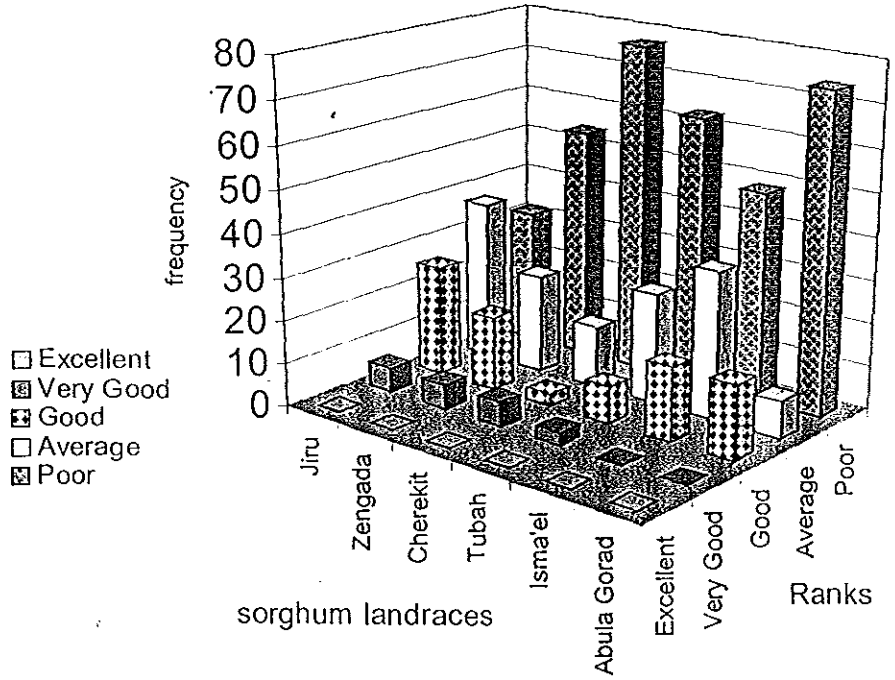

Figure 4: - Frequency of ranks given for medium ranking sorghum landraces as a food with different oil crops.

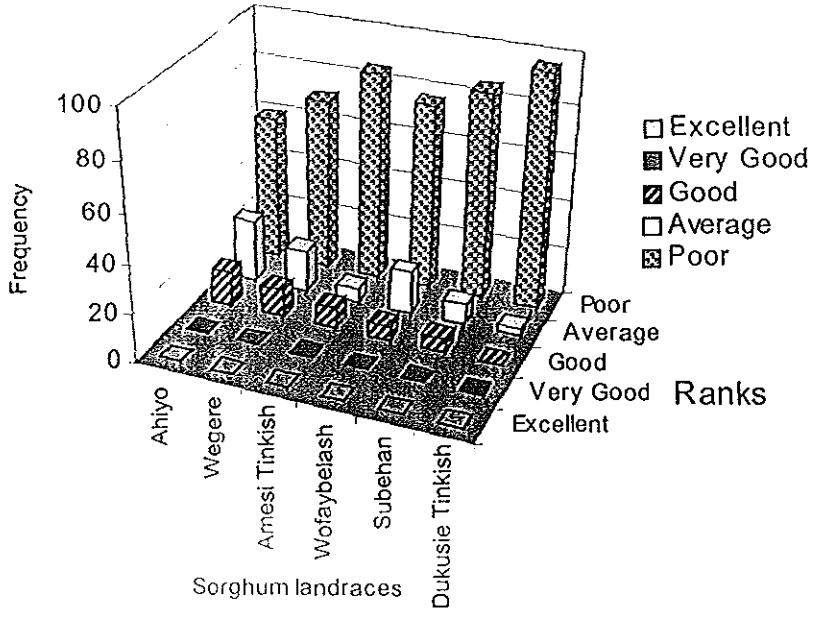

Figure 5: - Frequency of ranks given for low ranking sorghum landraces as a food with different oil crops.

5.1.2. COMPANIONSHIP OF SORGHUM AND EDIBLE OIL CROPS AT FIELD LEVEL

Chi-square test was conducted to test whether the six oil crops included in the study show similar companionship with sorghum at field level (Table 10). This analysis revealed that some oil crops are strongly and significantly (P=0.01) associated (as intercrop and/or boarder crop) with sorghum than others. Based on the analysis and Table 9 it is clear that sesame is the first oil crop that shows the strongest association with sorghum, which is followed by noog and Ethiopian mustard, while linseed is the least intercropped oil crop with sorghum, on the average.

Similarly, association of oil crops with sorghum as border crops and intercrops was analyzed using Z score test to see whether each oil crop is differently associated with sorghum. The analysis revealed that noog is strongly and significantly (P=0.01) border cropped than intercropped in sorghum fields (Table 12). On the other hand, sesame, Ethiopian mustard and safflower were significantly associated with sorghum as intercrops than as border crops (P=0.01, 0.01and 0.05. respectively). Ethnobotanical study on combined cropping of oil crops and sorghum has revealed that, on the average, 74.8% of the fields were intercropped, while the rest proportion is accounted for border cropping of which 19% was accounted by noog (Table 9). Considering the study sites separately, of sorghum fields with oil crops, intercropping accounts for 87.9%, 72.6%, 75%, 73.6%, 62.5% and 77.1% at Bati, Borkena Drainage, Haik, Laygnaw Ataye, Merewa Adere and Shewa Robit, respectively, (Fig. 6).

On the average, sesame is the most frequently intercropped oil crop and the second most frequently border cropped oil crop, next to noog, with average percent frequency of 38.97%

and 8.2%, respectively (Table 9, Fig. 7). Sunflower and linseed have shown lowest companionship with sorghum at the field level, and accounted for only 1.42% and 0.83% of intercropping and 0.72% and 2.15% border cropping of oil crops and sorghum, respectively (Table 9). The second most frequently intercropped oil crop in sorghum fields was Ethiopian mustard, which was followed by noog, safflower and sunflower, with average percent frequency of 18.7%, 8.25%, 3.33% and 1.42%, respectively.

5.1.3. COMPARISON OF ASSOCIATION OF OIL CROPS WITH SORGHUM AND TEF

Z score test analyzed for the equality of proportion of oil crops in sorghum fields and tef fields revealed that on the average, oil crops show significantly higher companionship with tef than with sorghum (Table 11). On the average, 94.88% of tef fields had at least one oil crop. Although it was not as high as tef fields, more than 50% of sorghum fields (51.34%) contain oil crop (see Fig. 9).

Noog was more frequently intercropped with sorghum (8.25%) than with tef (4.54%), while it was more frequently border cropped with tef (32.39%) than with sorghum (22.9%) (Table 9). Sesame was more frequently intercropped and border cropped with sorghum (38.97%) and 8.22%) than with tef (10.13%) and 0.52%), respectively.

Out of the six edible oil crops studied, the maximum number of species observed per field was three, in both sorghum and tef fields (Fig. 10 and 11). However, majority of such fields has one oil crop which accounted for 44.26% in sorghum fields and 63.64% in tef fields.

Sorghum and tef fields with two oil crops per field were 5.89% and 27.32%, respectively, while only 1.06% and 3.87% of sorghum and tef fields contained three oil crops per field.

Considering study sites, Borkena drainage, which has high sorghum diversity, was the area in which sorghum fields were most mixed cropped with oil crops (74.13%), while Merewa Adere was the least (35%) (Fig. 9). On the other hand, most frequent combined cropping in tef fields was recorded at Haik and Merewa Adere, which was 100%, and the least was Bati (85.71%). In general words, more than one species of edible oil crops were recorded in 31.19% tef fields and 6.94% sorghum fields (see Fig. 10&11).

Table 9- Frequencies of occurrence of edible oil crops as intercrops and border crops in Sorghum fields, at different sites

Sites	Oil crops														
	Intercropping frequencies (%)							Border cropping frequencies (%)							
	N	Se	L	Su	Sá	EM	T	N	Se	L	Su	Sa	EM	T	N*
Bati	10.8	43.4	1.2	4.8	9.6	18.1	87.9	2.4	0.0	0.0	2.4	7.4	0.0	12.0	83
Borkena Drainage	13.5	45.5	2.7	1.5	0.0	9.3	72.6	25.9	0.8	0.0	0.8	0.0	0.0	27.4	259
Haik	17.8	17.8	0.0	0.0	0.0	39.3	75	14.3	0.0	10.7	0.0	0.0	0.0	25.0	28
Laygnaw Ataye	1.1	60.4	1.1	2.2	0.0	8.8	73.6	11	11	2.2	1.1	0.0	1.1	26.4	91
Merewa Adere	0.0	25.0	0.0	0.0	0.0	37.5	62.5	37.5	37.5	0.0	0.0	0.0	0.0	37.5	8
Shewa Robit.	6.3	41.7	0.0	0.0	10.4	18.7	77.1	22.9	0.0	0.0	0.0	0.0	0.0	22.9	48
Mean	8.3	38.97	0.83	1.4	3.33	21.95	74.8	19	8.22	2.2	0.72	1.2	0.18	25.2	

N (Noog), Se (Sesame), L (Linseed), Su (Sunflower), Sa (Safflower), EM (Ethiopian Mustard), T (Total), N* (number of fields with oil crops)

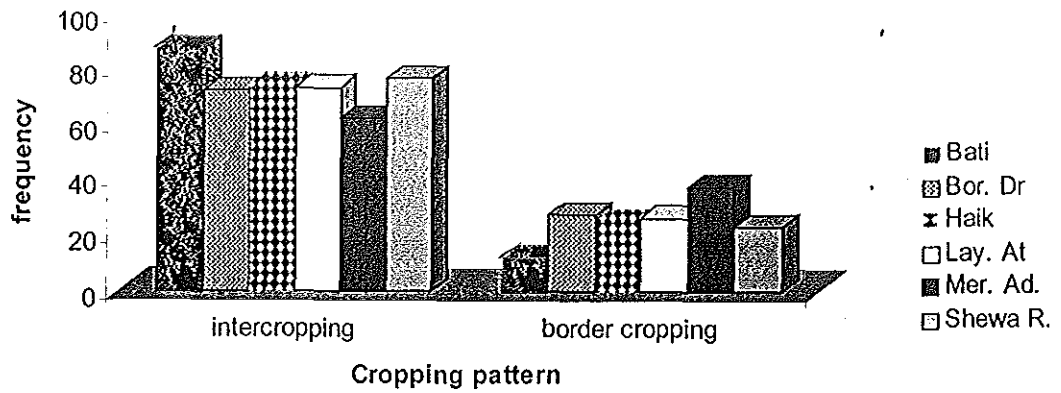

Figure 6: - Percent frequency of intercropping and border cropping of edible oil crops in sorghum fields in different study sites. Bor. Dr. (Borkena Drainage), Lay. At. (Laygnaw Ataye), Mer.Ad. (Merewa Adere), Shewa R. (Shewa Robit)

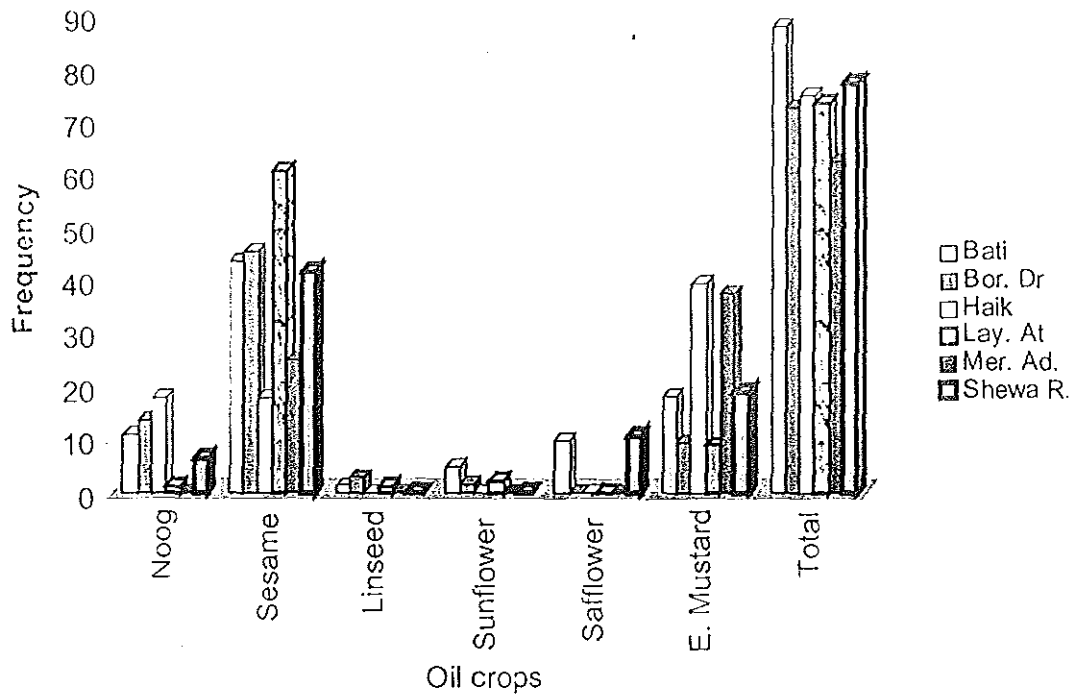

Figure 7. Intercropping frequency of different edible oil crops in sorghum fields at different study areas. For abbrev ations, refer to Fig. 6.

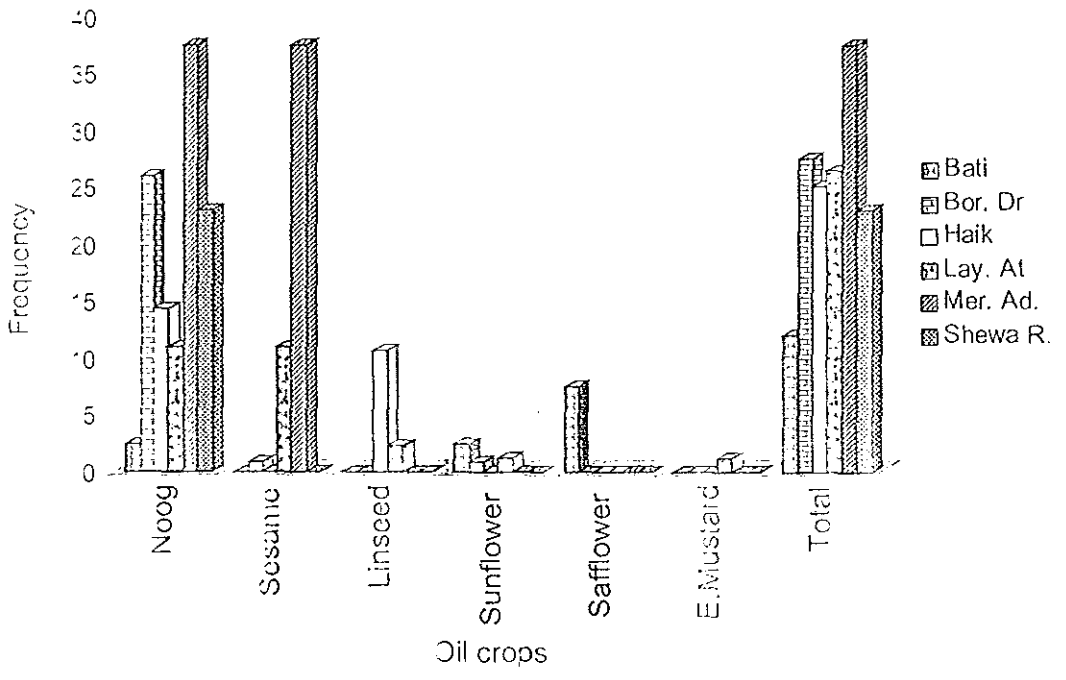

Figure 8. Percent Border cropping frequency of each edible oil crop and all oil crops considered together. For abbreviations, refer to Fig. 6.

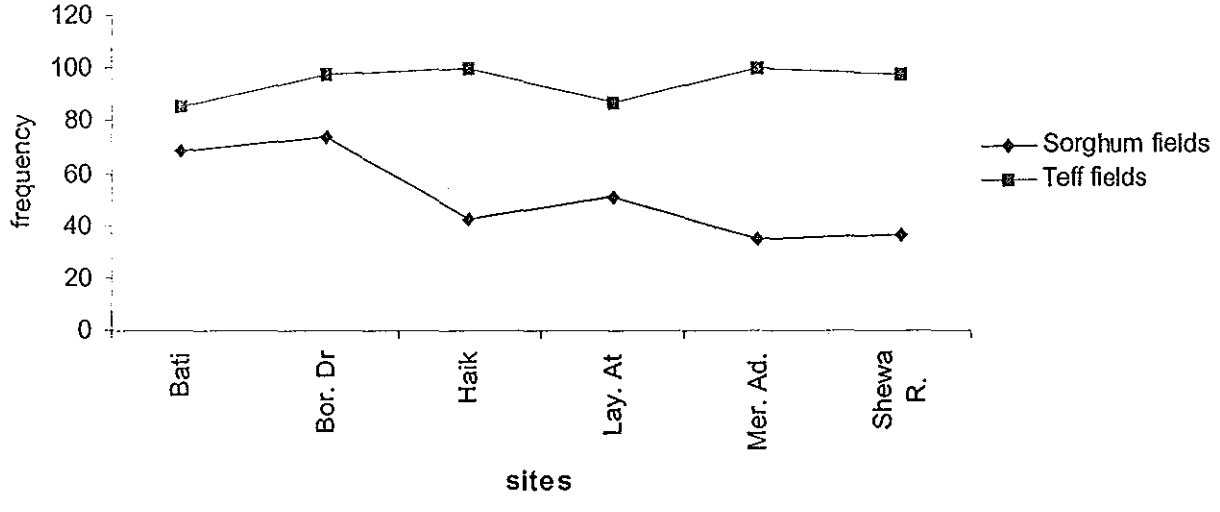

Figure 9: - Percent frequency of occurrence of edible oil crops in sorghum fields and tef fields at six areas. For abbreviations, refer to Fig. 6.

Table 10: -Chi square test for the distribution of each oil crop in sorghum fields with oil crops

Oil crops	Observed frequency	Expected frequency	X^2	Df	No of fields
Noog	150	86.17	525.459**	5	517
Sesame	248	86.17			
Linseed	14	86.17			
Sunflower	15	86.17			
Safflower	19	86.17			
Ethiopian mustard	71	86.17			

** Significant at P=0.01

Table 11: - Z score test for the frequency of occurrence of oil crops in tef fields and sorghum fields

Areas	Tef field		Sorghum field		Population proportion	Sigma	Z-test
	Sample proportion	Sample size	Sample proportion	Sample size			
Bati	0.857	21	0.684	114	0.711	0.108	1.607
Borkena Drainage	0.981	54	0.741	259	0.782	0.062	3.888**
Haik	1.000	86	0.426	61	0.762	0.071	8.050**
Laygnaw Ataye	0.871	31	0.512	168	0.568	0.097	3.707**
Merewa Adere	1.000	19	0.350	20	0.667	0.151	4.304**
Shewa Robit	0.981	108	0.367	109	0.673	0.064	9.637**
Total	0.948	319	0.513	731	0.645	0.032	13.534**

** Significant at P= 0.01(one tailed Z-test)

Table 12- Z- score test for the frequency of occurrence of each oil crop as intercrops and border crops in sorghum fields

Oil crops	% intercropping frequency (P_1)	No of Fields (n_1)	% border cropping frequency (P_2)	No of fields (n_2)	Population proportion	sigma	Z-test
Noog	0.083	517	0.190	517	0.136	0.021	-5.038**
Sesame	0.390	517	0.020	517	0.205	0.025	14.745**
Linseed	0.008	517	0.022	517	0.015	0.008	-1.746
Sunflower	0.014	517	0.007	517	0.011	0.006	1.096
Safflower	0.033	517	0.012	517	0.023	0.009	2.260*
Ethiopian mustard	0.220	517	0.002	517	0.111	0.020	11.155**

** Significant at P=0.01, * Significant at P=0.05

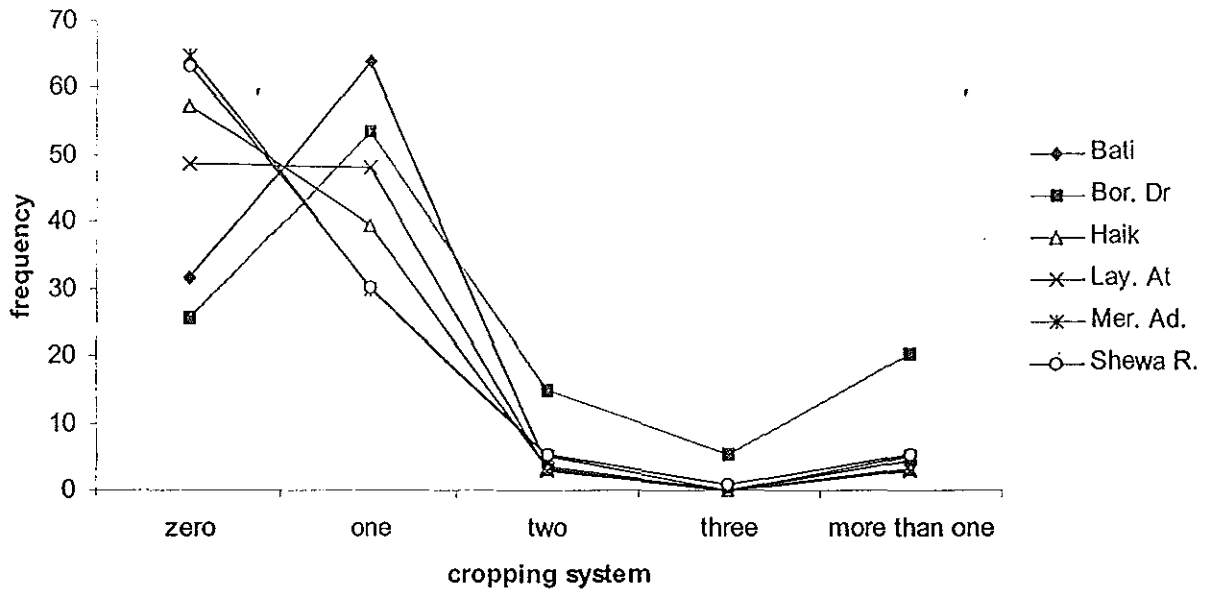

Figure 10: - Percent frequency of intercropping system in sorghum fields, at six areas. Zero, one, two, three and more than one refer to number of sorghum fields with no, one, two, three and more than one oil crops per field. For abbreviations, refer to Fig. 6.

Table 13 - Correlation analysis for mean numerical relationship between intercropped sorghum and some oil crops on field (per 16 m^2 area) at Fontenina

No	Oil Crop	Miazia sorghum	Hamle sorghum	Number of fields	Total no of 16 m^2 areas
1	Sesame	-0.172	_	15	75
2	Ethiopian mustard	-0.045	_	27	135
3	Ethiopian mustard	_	-1.00**	2	10
4	Noog	0.796*		4	20

** Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level

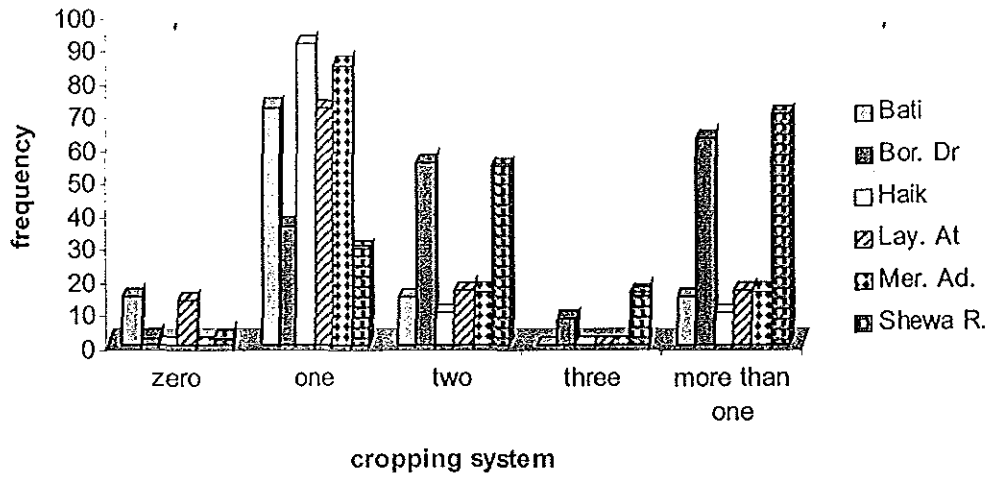

Figure 11: - Percent frequency of intercropping system in tef fields, at six areas. For details, see Fig. 6 and Fig.10.

Correlation analysis for the proportion of cereal crops (mainly sorghum and tef) with oil crops has shown that late maturing sorghum ("Miazia sorghum") was insignificantly correlated with Ethiopian mustard and sesame, while it has shown significant positive correlation (P=0.05) with noog. On the other hand, early maturing ("Hamle sorghum") intercropped in tef fields has shown perfect negative correlation with Ethiopian mustard cultivated within the same field (Table 13).

5.2. AGROMORPHOLOGICAL STUDY

5.2.1. ESTIMATES OF SHANNON'S DIVERSITY INDEX FOR QUALITATIVE CHARACTERS OF OIL CROPS

Tables 14, 15 and 16 show the estimates of diversity for each character for noog, sesame and safflower. Stem color and lodging show no variation for noog. All plants from both areas were characterized by purple stem color and very little lodging. Generally, there is less diversity for stem hairiness ($\hat{H}'$= 0.345) and leaf color ($\hat{H}'$= 0.499), and fairly high level of diversity for leaf margin (1.035).

There was no detectable variation in nine of the eleven qualitative characters of sesame. Plant materials on field at Shewa Robit and Bati were characterized by dehiscent capsule, square stem, green leaf, middle branching, broad oblong capsule with thick shell and brown color when dry, loose placental attachment and no lodging. This crop shows low diversity in stem color, exhibiting light green (20%) and green (80%) color. A fairly high diversity was calculated for seed color ($\hat{H}'$= 0.84) exhibiting light brown, brown and reddish brown colors.

No variation was recorded for nine of the eleven qualitative characters studied, in safflower (Table 16). All populations were characterized by closed outer involucral bracts with spines distributed all along margins and tip, conical capitulum, non-hairy light green leaves with ovate shape, serrate or dentate margin and many spines, and heads completely enclosed by bracts. The remaining two characters, growth habit and bract location, show intermediate level of diversity ($\hat{H}'$= 0.50). This crop exhibits two groups of growth habit, 64% erect and

36% bushy, and two groups of branch location, 64% branches predominantly on the upper two-third of the plant, and 36% branches from base to apex.

Table 14: -Estimates of SHANNON'S diversity index (H') for five qualitative characters of noog for two areas and mean diversity ($\hat{H}$) over areas and overall characters

Area	Phenotypic characters					
	Stem color	Leaf color	Leaf margin	Stem hairiness	Lodging	Mean
Borkena Drainage	0.00	0.998	1.05	0.69	0.00	0.548
Haik	0.00	0.00	1.02	0.00	0.00	0.204
Mean	0.00	0.499	1.035	0.345	0.00	0.376

Table 15: -Estimates of SHANNON's diversity index (H') for eleven qualitative characters of Sesame for two areas and mean diversity ($\hat{H}$) over areas and overall characters

Areas	Phenotypic characters											
	DHS	LOG	SM CR	SM SH	LF CR	BR H	CAP SH	CAP CR	PLA ATT	SH THI	SD CR	Mean
Bati	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.05	0.16
Shewa Robit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.06
Mean	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.84	0.11

DHS (dehiscence), LOG (lodging), SMCR (stem color), SMSH (stem shape), LFCR (leaf color), BRH (branching habit), CAPSH (capsule shape), CAPCR (capsule color), PLA ATT (placental attachment), SHTHI (shell thickness) and SDCR (seed color).

Table 16: - Estimates of SHANNON'S diversity index (H') for eleven qualitative characters of Safflower for five populations and mean diversity ($\hat{H}$) over populations and overall characters

popula	Phenotypic Characters											
tion	OLB ATT	SP LOC	CAP SH	GR H	BR LOC	LF SH	LF MA	LF CR	LF SP	LF HR	BR EN	Mean
1	0.00	0.00	0.00	0.67	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.12
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.67	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.12

4	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.09
5	0.00	0.00	0.00	0.67	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.12
mean	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.09

OLBATT (outer involucral bract attachment), SPLOC (spine location), CAPSH (capitulum shape), GRH (growth habit), BRLOC (branch location), LFSH (leaf shape), LFMA (leaf margin), LFCR (leaf color), LFSP (leaf spineness), LFHR (leaf hairiness) and BREN (bract enclosure).

5.2.2. ANALYSIS OF VARIANCE FOR QUANTITATIVE AGROMORPHOLOGICAL CHARACTERS OF OIL CROPS

Sesame was characterized for seven quantitative agromorphological characters, of which number of capsules per axil and number of locules per capsule did not show any variation. All plants were characterized by one capsule per axil and four locules per capsule (Table 17). Analysis of variance (ANOVA) for these agromorphological characters of sesame indicated that plant height, ($F= 73.13$; $P< 0.0001$), number of capsules per plant ($F=38.56$; $P<0.0001$), capsule length ($F=8.61$; $P=0.01$), number of seeds per capsule ($F=19.73$; $P< 0.0001$) and number of branches per plant ($F=16.61$; $P< 0.0001$) show significant variation between Shewa Robit and Bati (Table 20). On the other hand, variation between populations within the site (for both Shewa Robit and Bati) was not significant, except number of seeds per capsule ($F= 17.14$; $P< 0.0001$) at Shewa Robit (Table 22).

Noog was characterized for eight quantitative characters. Angle of branching was totally uniform, which fall in intermediate category (<90 ^{o} but not very erect). Analysis of variance revealed significant variation in bract width ($F=3.44$, $P< 0.05$) between populations from Borkena drainage. However, variation in this character is insignificant for Haik. Number of heads per plant ($F=4.75$; $P=0.01$) and number of nodes ($F=3.14$; $P< 0.05$) were significantly

different for Haik (Table 21). Number of primary branches (F= 40.27; P< 0.0001), number of heads per plant (F=18.44; P< 0.0001), leaf length (F=36.00; P< 0.0001), leaf width (F=6.00; P< 0.05) and head size show significant variation between Borkena drainage and Haik. In contrary, variation in plant height, which was significant between populations of Borkena drainage was insignificant between Borkena drainage and Haik (Table 20).

Safflower from Shewa Robit was characterized for nine agromorphological traits. Results of analysis of variance have shown that internode length (F= 12.00; P< 0.0001), outer involueral bracts length (F= 7.23; P< 0.001) and outer involueral bracts width (F= 4.79; 0.01) were significant between populations. Seed size, angle of branching and outer involueral bract spines show no variation (Table 22). Sunflower from Borkena drainage was characterized for eight agromorphological characters, of which bract length (length of leafy structure around primary heads) (F= 2.22; P= 0.1), bract width (F=3.44, P< 0.05) were significantly variable among populations. There was no variation in angle of branching, among all plants characterized (Table 21)

Of five quantitative characters, variation between populations of linseed from Haik was significant for number of balls per plant (F= 3.3; P; 0<05) and plant height (F= 14.5; P, 0.0001) only (Table 22). Ethiopian mustard from Borkena drainage was analyzed for seven quantitative characters, of which only capsule width (F= 2.93; P< 0.05) and number of primary branch per plant (F= 4.89; P< 4.89; P< 0.01) were significantly different between populations (Table 20).

Table 17: -Maximum, minimum, mean and standard error values and 95% confidence interval for quantitative characters of sesame and sunflower from three sites

Characters	N	Mean±SE	95% Confidence Interval for Mean		Minimum	Maximum	Oil crop	Area
			Lower Bound	Upper Bound				
PH	25	144±5.26	133.12	154.84	75	182	Sesame	Shewa Robit
NCPA	25	1±0.00	1	1	1	1		
NCPP	25	360±36.44	284.75	435.17	48	938		
CL	25	29.8±0.45	28.87	30.73	27	34		
NSPC	25	83.04±2.29	78.31	87.77	68	96		
NLPC	25	4±0.00	4	4	4	4		
NB	25	7.92±0.53	6.82	9.02	2	12		
PH	25	192.26±2.04	188.04	196.48	176	207	Sesame	Bati
NCPA	25	1±0.00	1.00	1.00	1	1		
NCPP	25	129.64±6.91	115.37	143.91	47	223		
CL	25	28.16±0.33	27.48	28.84	26	31		
NLPC	25	4±0.00	4.00	4.00	4	4		
NSPC	25	72.32±0.76	70.74	73.90	68	80		
NB	25	10.88±0.49	9.86	11.90	6	15		
AB	25	5.00±0.00	5.00	5.00	5	5	Sunflower	Borkena Drainage
BRL	25	9.58±0.31	8.94	10.22	6.3	11.6		
BRW	25	4.67±0.12	4.42	4.93	3.6	5.9		
DPH	25	30.62±1.83	26.85	34.39	18	45		
LL	25	37.67±1.66	34.25	41.09	26	54.2		
LW	25	34.98±1.73	31.42	38.55	20.4	50.5		
NHPP	25	4.44±1.60	1.15	7.73	1	39		
NLPP	25	34.48±2.59	29.13	39.83	18	62		
PH	25	198.44±4.99	188.15	208.73	160	240		
SDSZ	25	5.00±0.00	5.00	5.00	5	5		

PH (plant height), NCPA (number of capsules per axil), NCPP (number of capsules per plant), CL (Capsule length), NSPC (number of seeds per capsule), NLPC (number of locules per capsule), NB (number of branches) AB (Angle of branching), BRL (Bract length), BRW (Bract width), DPH (diameter of primary head), LL (Leaf length), LW (Leaf width), NHPP (number of heads per plant), NLPP (number of locules per plant), SDSZ (seed size).

Table 18: -Maximum, minimum, mean, standard error values and 95% confidence interval values for quantitative characters of safflower, linseed and Ethiopian mustard at different sites

Characters	N	Mean±SE	95% Confidence Interval for Mean		Minimum	Maximum	Oil crop	Area
			Lower Bound	Upper Bound			Safflower	Shewa Robit
AB	25	5±0	5	5	5	5		
CAPNO	25	158.52±9.19	139.54	177.50	64	219		
DPH	25	19.44±0.15	19.13	19.75	18	20.5		
INL	25	4.36±0.19	3.97	4.75	3	5		
OLBL	25	30.1±0.36	29.35	30.85	28	34		
OLBS	25	7±0	7	7	7	7		
OLBW	25	10.6±0.31	9.96	11.24	5	12		
PH	25	111.36±4.75	101.56	121.16	52	143		
SDSZ	25	5.4±0.16	5.06	5.74	5	7		
NBB	25	4.56±0.28	3.97	5.14	2	7	Linseed	Haik
NBOPP	25	17.2±2.14	12.77	21.63	5	46		
NSDPB	25	8.92±0.32	8.26	9.58	5	10		
NUPB	25	4.88±0.28	4.29	5.47	2	7		
PH	25	62.31±3.05	56.026	68.60	29.5	83.1		
CL	25	4.108±0.10	3.9	4.31	3.4	4.9	Ethiopian Mustard	Borkena Drainage
CW	25	4.06±0.11	3.8	4.28	3.5	5		
NCPP	25	1324±78.19	1162.6	1485.38	720	2095		
NNPP	25	21.48±0.74	20.0	23.01	14	27		
NSDPC	25	19.6±0.42	18.7	20.47	16	23		
PH	25	140.88±3.08	134.5	147.24	116	161		
	25	23.32±1.35	20.5	26.10	12	33		

CAPNO (number of capitulum per plant), INL (internode length), OLBS (number of spines per outer involucral bract), OLBL (outer involucral bract length), OLB W (outer involucral bract width), NBB (number of basal branches), NBOPP (number of balls per plant), NSDPB (Number of seeds per ball), NUPB (number of upper branchs, CW (capsule width), NSDPC (number of seeds per capsule), NNPP (number of nodes per plant), PBPP (primary branches per plant), For other abbreviations, refer to Table 17.

Table 19: -Maximum, minimum, mean and standard error values and 95% confidence interval for quantitative characters of noog from Borkena Drainage and Haik

Traits	N	Mean±SE	95% Confidence Interval for Mean		Minimum	Maximum	Oil crops	Area
			Lower Bound	Upper Bound				
AB	25	3±0.00	3.00	3.00	3	3	Noog	Borkena Drainage
HSZ	25	2.6±0.23	2.12	3.08	1	5		
LL	25	4.2±0.20	3.79	4.61	3	5		
LW	25	3.4±0.16	3.06	3.74	3	5		
NHP	25	820.56±143.72	523.93	1117.19	172	3910		
NNP	25	12.44±0.65	11.10	13.78	8	19		
NPB	25	20.56±1.00	18.49	22.63	13	31		
PH	25	126.84±4.90	116.73	136.95	87	185		
AB	25	3±0.00	3.00	3.00	3	3	Noog	Haik
HSZ	25	1.8±0.20	1.39	2.21	1	3		
LL	25	3±0.00	3.00	3.00	3	3		
LW	25	3±0.00	3.00	3.00	3	3		
NHPP	25	199.96±15.32	168.34	231.58	36	310		
NNPP	25	13.12±0.57	11.94	14.30	10	18		
NPB	25	13.52±0.47	12.54	14.50	9	17		
PH	25	125.12±5.76	113.24	137.00	59.5	202		

HSZ (Head size), NHPP (number of heads per plant) and NPB (number of primary branches). For other abbreviations, refer to Table 17&18.

Table 20: - Mean squares for the variation in sesame, safflower and linseed within and between farms, from analysis of variance (ANOVA) for each quantitative character

Characters	Mean square within Area (df=48)	Mean square Between areas(df=1)	F	Oil crop	Area
AB	0.00	0.00	.	Noog	Haik + Borkena Drainage
HSZ	8.00	1.17	6.86**		
LL	18.00	0.50	36.00**		
LW	2.00	0.33	6.00*		
NHP	4814304.50	261131.44	18.44**		
NNP	5.78	9.35	0.62		
NPB	619.52	15.38	40.27**		
PH	36.98	714.28	0.05		
CL	33.62	3.90	8.61**	Sesame	Shewa Robit + Bati
NB	109.52	6.59	16.61**		
NCPA	0	0	.		
NCPP	663091.28	17194.77	38.56**		
NLPC	0	0	.		
NSPC	1436.48	72.8	19.73**		
PH	29136.98	398.43	73.13**		

*= Significant at P=0.05, **= Significant at 0.01. For abbreviations, refer to Table 17-19.

Table 21: - Mean squares for the variation in sunflower, noog and Ethiopian mustard within and between farms, from analysis of variance (ANOVA) for each quantitative character

Traits	Mean square within farms (df=20)	Mean square Between farms (df=4)	F	Oil crop	Area
AB	0	0	.	Sunflower	Borkena Drainage
BRL	4.407	1.9876	2.22		
BRW	0.9316	0.2712	3.44*		
DPH	162.71	67.765	2.40		
LFL	12.0856	79.9304	0.15		
LFW	24.1874	84.5012	0.29		
NHPP	68.24	62.76	1.09		
NLPP	193.56	162.8	1.19		
PH	302.14	685.78	0.44		
SDSZ	0	0	.		
AB	0	0	.	Noog	Haik
HSZ	0.4	1.12	0.36		
LL	0	0	.		
LW	0	0	.		
NHP	17146.54	3610.54	4.75**		
NNP	18.96	6.04	3.14*		
NPB	10.56	4.6	2.30		
PH	658.685	861.97	0.76		
AB	0	0	.	Noog	Borkena Drainage
HSZ	2.8	2.8	2.69		
LL	6	0	.		
LW	4	0	.		
NHP	409383.14	537798.98	0.76		
NNP	10.04	10.6	0.95		
NPB	3.94	29.42	0.13		
PH	1577.44	405.08	3.89*		
CL	0.0526	0.2804	0.19	Ethiopian mustard	Borkena Drainage
CW	0.615	0.21	2.93*		
NCPP	250900	133248.7	1.88		
NNPP	14.96	13.42	1.11		
NSDPC	7.1	3.88	1.83		
PH	278.06	229.42	1.21		
PRPP	134.16	27.44	4.89		

*= Significant at P=0.05, **= Significant at 0.01. For abbreviations, refer to Table 17-19.

Table 22: - Mean squares for the variation sesame, safflower and linseed within and between farms from analysis of variance (ANOVA) for individual quantitative characters

Characters	Mean square within farms (df=20)	Mean square Between farms (df=4)	F	Oil crop	Area
PH	1229.34	585.22	2.10	Sesame	Shewa Robit
NCPA	0.00	0.00	.		
NCPP	68774.74	26078.40	2.64		
CL	3.60	5.38	0.67		
NSPC	608.64	35.52	17.14**		
NLPC	0.00	0.00	.		
NB	4.66	7.56	0.62		
PH	82.67	108.62	0.76	Sesame	Bati
NCPA	0	0	.		
NCPP	1590.54	1115.98	1.43		
CL	1.74	2.92	0.6		
NSPC	0	0	.		
NLPC	7.36	16	0.46		
NB	6.46	6.04	1.07		
AB	0	0	.	Safflower	Shewa Robit
CAPNO	1822.66	2171.48	0.84		
DPH	0.565	0.57	0.99		
INL	3.84	0.32	12**		
OLBL	11.825	1.635	7.23**		
OLBS	0	0	.		
OLBW	6.975	1.455	4.79**		
PH	448.54	587.08	0.76		
SDSZ	4	0	.		
NBB	3.14	1.78	1.76	Linseed	Haik
NBOPP	274.2	83.16	3.3*		
NSDPB	2.36	2.62	0.9		
NUPB	0.86	2.26	0.38		
PH	1035.1526	71.2568	14.5**		

*= Significant at P=0.05, **= Significant at 0.01. For abbreviations, refer to Table 17-18.

5.2.3. CORRELATION ANALYSIS OF QUANTITATIVE AGROMORPHOLOGICAL CHARACTERS OF OIL CROPS

Correlation analysis for seven quantitative characters of sesame has revealed that capsule length was significantly and positively correlated with number of capsules per plant and number of seeds per capsule (P=0.01), while it was significantly and negatively correlated with plant height (P=0.01) (Table 23). Plant height was also significantly and negatively correlated with number of capsules per plant (P=0.01). Number of branches per plant showed significant negative correlation with number of seeds per capsule (P=0.05), while it was significantly and positively correlated with plant height (P=0.05).

In noog, leaf length was significantly and positively correlated with leaf width, number of heads per plant and number of primary branches (P=0.01) (Table 24). Plant height was significantly and positively correlated with number of nodes per plant (P=0.05) and number of heads per plant (P=0.05).

In sunflower, bract length showed significant positive correlation with bract width (P=0.01), leaf length (P=0.05) and leaf width (P=0.05). Leaf length was significantly and negatively correlated with diameter of primary head (P=0.05), while it showed significant positive correlation with leaf width (P=0.01). Linseed showed significant positive correlation between number of basal branches and number of upper branches (Table 26). In Ethiopian mustard, number of capsules per plant was positively and significantly correlated with primary branch per plant and plant height (P=0.01). Plant height showed significant positive correlation with primary branch per plant (P=0.01) (Table 27). In safflower, outer involucral bract width had

significant negative correlation with seed size (P=0.01) and internode length (P=0.05). On the other hand, seed size was significantly and positively correlate with outer involucral bract length (P=0.05) (Table 28).

Table 23: -Table: -Pearson correlation coefficient of quantitative characters of *Sesamum indicum*

Traits	CL	NB	NCPA	NCPP	NLPC	NSPC	PH	N
CL	1	-0.21	.a	0.48**	.a	0.41**	-0.45**	50
NB	-0.21	1	.a	0.08	.a	-0.36**	0.36**	
NCPA	.a	.a	.a	.a	.a	.a	.a	
NCPP	0.48**	0.08	.a	1	.a	0.18	-0.57**	
NLPC	.a	.a	.a	.a	.a	.a	.a	
NSPC	0.41**	-0.36*	.a	0.18	.a	1	-0.25	
PH	-0.45**	0.36*	.a	-0.57**	.a	-0.25	1	

For abbreviations, refer to Table 17. N (number of individual plants),** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed), .a cannot be computed because at least one of the variables is constant.

Table 24: -Pearson correlation coefficient of quantitative characters of *Guizotia abyssinica*

Characters	AB	HSZ	LL	LW	NHP	NNP	NPB	PH	N
AB	.a	.a	.a	.a	.a	.a	.a	.a	
HSZ	.a	1	0.15	-0.24	-0.06	-0.18	0.07	-0.07	50
LL	.a	0.15	1.00	0.51**	0.40**	0.09	0.41**	0.27	
LW	.a	-0.24	0.51**	1.00	0.07	0.09	0.20	-0.01	
NHP	.a	-0.06	0.40**	0.07	1.00	0.08	0.73**	0.28*	
NNP	.a	-0.18	0.09	0.09	0.08	1.00	-0.05	0.34*	
NPB	.a	0.07	0.41**	0.20	0.73**	-0.05	1.00	0.17	
PH	.a	-0.07	0.27	-0.01	0.28*	0.34*	0.17	1.00	

For abbreviations, refer to Table 17-19. N (number of individuals), ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed),.a Cannot be computed because at least one of the variables is constant.

Table 25: -Pearson correlation coefficient of quantitative characters of *Helianthus annuus*

Characters	AB	BRL	BRW	DPH	LFL	LWW	NHPP	NLPP	PH	SDSZ	N
AB	.a	.a	.a	.a	.a	.a	.a	.a	.a	.a	25
BRL	.a	1.00	0.62**	0.10	0.41*	0.40*	-0.29	-0.33	0.06	.a	
BRW	.a	0.62**	1.00	0.24	0.31	0.32	-0.41*	-0.04	0.10	.a	
DPH	.a	0.10	0.24	1.00	-0.42*	-0.36	-0.07	0.04	0.04	.a	
LFL	.a	0.41*	0.31	-0.42*	1.00	0.96**	-0.25	-0.29	-0.11	.a	
LWW	.a	0.40*	0.32	-0.36	0.96**	1.00	-0.13	-0.23	-0.21	.a	
NHPP	.a	-0.29	-0.41*	-0.07	-0.25	-0.13	1.00	0.15	-0.28	.a	
NLPP	.a	-0.33	-0.04	0.04	-0.29	-0.23	0.15	1.00	0.04	.a	
PH	.a	0.06	0.10	0.04	-0.11	-0.21	-0.28	0.04	1.00	.a	
SDSZ	.a	.a	.a	.a	.a	.a	.a	.a	.a	.a	

For abbreviations, refer to Table 17.N (number of individuals), ** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed), .a Cannot be computed because at least one of the variables is constant.

Table 26: -Pearson correlation coefficient of quantitative characters of *Linum usitatissimum*

Characters	NBB	NUPB	PH	NBOPP	NSDPP	N
NBB	1.00	0.47*	-0.03	-0.02	-0.22	25
NUPB	0.47*	1.00	0.07	0.30	-0.04	
PH	-0.03	0.07	1.00	0.17	-0.31	
NBOPP	-0.02	0.30	0.17	1.00	-0.06	
NSDPB	-0.22	-0.04	-0.31	-0.06	1.00	

For abbreviations, refer to Table 17-18. N (number of individuals),* Correlation is significant at the 0.05 level (2-tailed).

Table 27: -Pearson correlation coefficient of quantitative characters of *Brassica carinata*

Traits	NCPP	CL	CW	NSDPC	NNPP	PBPP	PH	N
NCPP	1.00	-0.16	0.10	-0.11	-0.13	0.60**	0.57**	25
CL	-0.16	1.00	0.34	-0.02	-0.11	0.07	0.00	
CW	0.10	0.34	1.00	0.04	-0.11	0.05	-0.36	
NSDPC	-0.11	-0.02	0.04	1.00	-0.05	-0.03	-0.02	
NNPP	-0.13	-0.11	-0.11	-0.05	1.00	-0.15	0.00	
PBPP	0.60**	0.07	0.05	-0.03	-0.15	1.00	0.53**	
PH	0.57**	0.00	-0.36	-0.02	0.00	0.53**	1.00	

For abbreviations, refer to Table 17-18. N (number of individuals),** Correlation is significant at the 0.01 level (2-tailed).

Table 28: -Pearson correlation coefficient of quantitative characters of *Carthamus tinctorius*

Characters	AB	PH	DPH	CAPNO	OLBS	OLBL	OLBW	SDSZ	INL	N
AB	.a	.a	.a	.a	.a	.a	.a	.a	.a	25
PH	.a	1	0.24	-0.34	.a	0.34	0.30	-0.06	0.01	
DPH	.a	0.24	1.00	-0.04	.a	0.25	-0.07	0.38	0.18	
CAPNO	.a	-0.34	-0.04	1.00	.a	-0.2	-0.12	-0.05	-0.21	
OLBS	.a	.a	.a	.a	.a	.a	.a	.a	.a	
OLBL	.a	0.34	0.25	-0.20	.a	1	0.07	0.45*	0.09	
OLBW	.a	0.30	-0.07	-0.12	.a	0.07	1.00	-0.63**	-0.41*	
SDSZ	.a	-0.06	0.38	-0.05	.a	0.45*	-0.63**	1.00	0.34	
INL	.a	0.01	0.18	-0.21	.a	0.09	-0.41*	0.34	1.00	

For abbreviations, refer to Table 17-18.N (in umber of individuals), * Correlation is significant at the 0.05 level (2-tailed), ** Correlation is significant at the 0.01 level (2-tailed), .a Cannot be computed because at least one of the variables is constant.

5.3. ISOZYME ANALYSIS

Using the three enzyme systems (Aspartate aminotransferase [AAT], Leucine aminopeptidase [LAP] and a-Esterase [a-EST]), three AAT loci, three LAP loci and four EST loci were detected. However, only the second locus of AAT, the second locus of LAP, the first and the third loci of EST were constantly detected and repeatable in all populations. Thus, only these consistent bands were used for analysis.

5.3.1.AVERAGE GENE FREQUENCIES AND ITS DISTRIBUTION AMONG POPULATIONS

AAT-2

At AAT-2 locus, three allozymes were revealed (Tables 29, 31 and 33). In both *in situ* and *ex situ* conserved populations, allozyme B possesses the highest frequencies and is fixed in six *in situ* populations and six *ex situ* populations. The least frequency of allele B is 0.2 for both

groups. It is recorded in population 24I, for *in situ* and population 13E for *ex situ* conserved populations.

In the *in situ* conserved populations allele A is restricted to only four populations (4I, 7I, 13I and 24I) at frequencies of 0.2, 0.3, 0.4 and 0.8 respectively. The maximum frequency of this allele is recorded in population 24I (P=0.8). In the *in situ* conserved group allele C is distributed among populations more than allele A, and fixed in one population (9I).

Unlike *in situ* conserved populations, *ex situ* conserved populations allele C is less distributed among populations. The highest frequency recorded for this allele is 0.4, which was recorded in two populations (12E and 13E). For this group, allele A has better distribution and it was recorded in eleven populations, and the highest allelic frequency (P=0.4) was recorded in three populations (13E, 21E, 21E).

LAP-2

The pattern of this locus is characterized by highest frequency of allozyme B followed by allele A and a rarity of C and D allozymes in both *in situ* and *ex situ* conserved populations (Tables 29, 31 and 34). Allele B is detected in all populations studied, and fixed in three *in situ* conserved populations (14I, 15I and 24I), and four *ex situ* conserved populations (4E, 9E, 14E and 16E). The lowest frequency for this allele is 0.5 in the *in situ* populations, and detected in four populations (3I, 4I, 7I and 27I). While in the case of *ex situ* populations, the lowest frequency detected was 0.2 (recorded for population 19I and 22I). Allele A was not common for all populations. It is absent in seven *in situ* and, seven *ex situ* populations. The

highest frequency for this allele is 0.4 (27I) among *in situ* populations and 0.667 for (16E) among *ex situ* populations.

In *in situ* populations, the two rare alleles (allele C and D) were detected only in 10 populations and four populations, respectively. The highest frequency of allele C is 0.4, detected in two populations (5I and 7I), and allele D has highest frequency with equal magnitude as allele C; however, it is detected only in 4I. In *ex situ* populations similar pattern was recorded. Allele C was recorded in two populations, while allele D was detected in three populations. These alleles has equal highest frequency (P=0.3), detected in two populations (22E and 25E) and in one population (19E) for allele C and D, respectively.

EST-1

Out of the seven allozymes recorded at this locus, the most common was allozyme C, which is fixed in three populations (13I, 24I, 29I), in *in situ* conserved group and in two populations (9E and 21E), in *ex situ* conserved group (Tables 29, 31 and 36). The mean allelic frequency for this allele was 0.538 and 0.610 in *in situ* and *ex situ* groups, respectively. Allele D was the second in mean frequency for both *in situ* and *ex situ* groups, which was 0.171 and 0.116, respectively. The highest frequency of this allele was recorded in population 17 (P=0.6) and population 13 (P=0.7) in *in situ* and *ex situ* groups, respectively.

Allele A, E and G are rare alleles. In *in situ* group, allele A was detected only in two populations (2I and 22I), allele E was detected only in one population (27I) and allele G was detected in four population (3I, 9I, 19I and 28I). For the *ex situ* group allele A had a better

distribution as compared to the *in situ* group and recorded in five populations, while allele E and D was restricted to only two and three populations.

EST-3

At this locus, allele B is the most common allele (Table 29, 31 and 35). It occurred at mean frequency of 0.871 and 0.810 in *in situ* and *ex situ* groups, respectively. This allele was fixed in eight *in situ* populations and seven *ex situ* populations. In the case of *in situ* populations, the rest three alleles (A, C and D) were found with a mean frequency of 0.024, 0.081 and 0.025, respectively, which could be considered as rare alleles. For *ex situ* conserved group, these alleles were found with a mean gene frequency of 0.036, 0.129 and 0.025, for allele A, C and D, respectively. In other words, allele A and C has got a relatively higher frequency in *ex situ* groups as compared to *in situ* groups, while allele A was equal in frequency in both groups.

Allele C was the second in distribution and was recorded in nine *in situ* populations and 12 *ex situ* populations. However, the highest frequency for this allele is 0.4 (population 3I and 7I) and 0.5 (population 21E) for *in situ* and *ex situ* groups, respectively. Allele A is restricted to only three populations (12I, 19I and 27I) for the *in situ* group, however a better distribution was recorded in *ex situ* populations, for this allele. Allele D was restricted in four *in situ* populations, and only two *ex situ* populations. The highest frequency recorded for allele D was 0.2 (population 8I) for the *in situ* and 0.3 (population 23E) for the *ex situ* group.

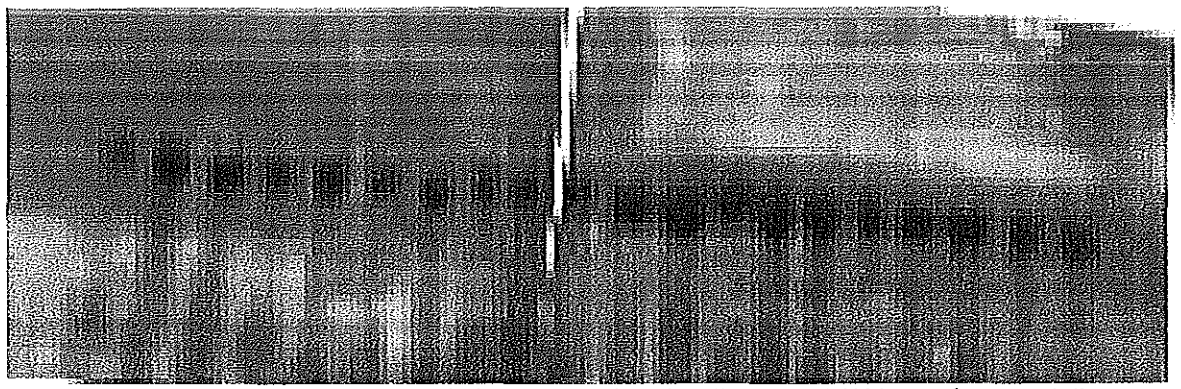

Figure 12: - Photograph of starch gel showing the band patterns at AAT locus for Population 13I.

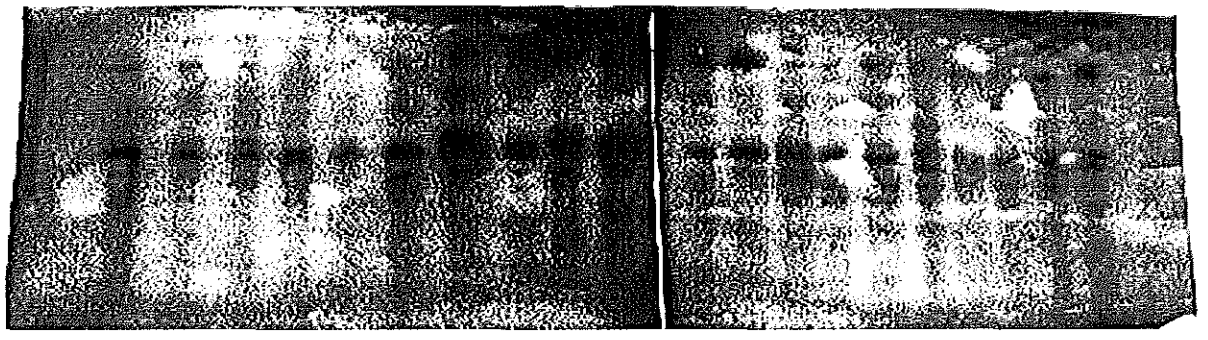

Figure 13: - Photograph of starch gel showing the band patterns at LAP loci for Population 11E

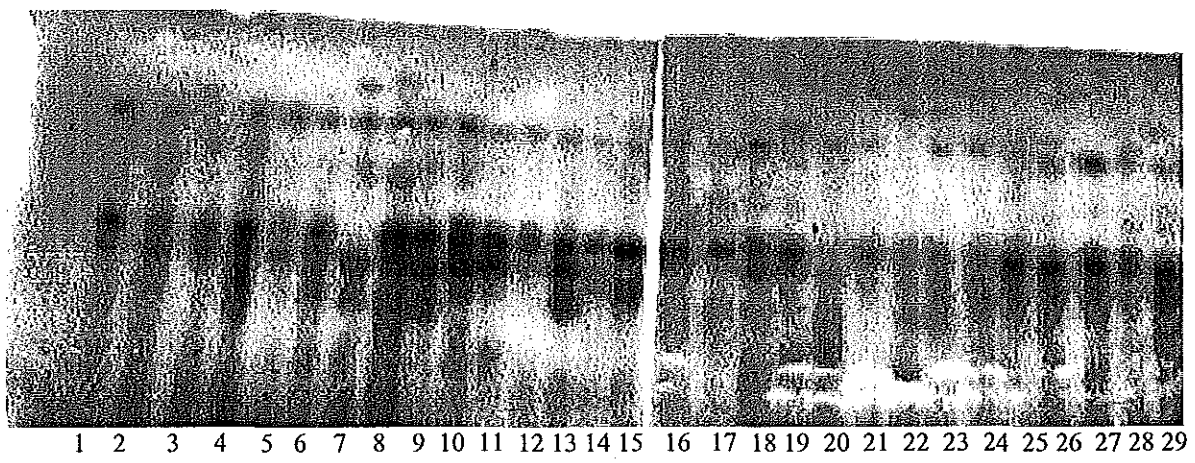

Figure 14: - Photograph of starch gel showing the band patterns at EST loci for 1E (1-5), 2E (6-10), 4E (11-15), 19E (16-20), 20E (21-25) and 21E (26-29), respectively.

Table 29: -Allele frequencies in twenty *in situ* conserved populations

Locus	Populations																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AAT-2																				
(N)	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5
A	.000	.000	.200	.000	.300	.000	.000	.000	.400	.000	.000	.000	.000	.000	.000	.800	.000	.000	.000	.000
B	.800	1.00	.800	.800	.300	.750	.000	.400	.600	1.00	.800	.800	.800	.400	1.00	.200	.600	1.00	1.00	1.00
C	.200	.000	.000	.200	.400	.250	1.00	.600	.000	.000	.200	.200	.200	.600	.000	.000	.400	.000	.000	.000
LAP-2																				
(N)	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	5
A	.300	.300	.000	.000	.000	.300	.100	.300	.300	.000	.000	.100	.200	.100	.200	.000	.100	.400	.000	.100
B	.700	.500	.500	.600	.500	.600	.900	.600	.700	1.00	1.00	.800	.600	.900	.800	1.00	.900	.500	.900	.800
C	.000	.100	.100	.400	.400	.100	.000	.100	.000	.000	.000	.100	.200	.000	.000	.000	.000	.100	.000	.100
D	.000	.100	.400	.000	.100	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.100	.000
EST-1																				
(N)	4	5	5	5	3	3	5	5	5	4	5	5	5	5	5	3	5	5	4	4
A	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.100	.000	.000	.000	.000	.000	.000
B	.125	.200	.000	.000	1.00	.833	.000	.000	.000	.000	.000	.000	.200	.100	.000	.000	.000	.100	.125	.000
C	.625	.200	.800	.600	.000	.000	.500	.500	1.00	.500	.500	.600	.200	.300	.800	1.00	.300	.700	.625	1.00
D	.000	.000	.100	.000	.000	.000	.400	.500	.000	.125	.500	.000	.500	.500	.200	.000	.600	.000	.000	.000
E	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.100	.000	.000
F	.250	.300	.100	.400	.000	.167	.000	.000	.000	.375	.000	.400	.000	.000	.000	.000	.100	.100	.000	.000
G	.000	.100	.000	.000	.000	.000	.100	.000	.000	.000	.000	.000	.100	.000	.000	.000	.000	.000	.250	.000
EST-3																				
(N)	5	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	4	4	5
A	.000	.000	.000	.000	.000	.000	.000	.100	.000	.000	.000	.000	.125	.000	.000	.000	.000	.250	.000	.000
B	.800	.500	.800	.900	.400	.800	1.00	.900	1.00	.900	1.00	.900	.875	1.00	1.00	1.00	1.00	.750	.875	1.00
C	.200	.400	.100	.100	.400	.100	.000	.000	.000	.100	.000	.100	.000	.000	.000	.000	.000	.000	.125	.000
D	.000	.100	.100	.000	.200	.100	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

Table 30: - Matrix of distance coefficients (Nei, 1978 unbiased minimum distance) for twenty *in situ* conserved populations

Pop	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	6	17	18	19	20
1	****																			
2	.013	****																		
3	.014	.068	****																	
4	.000	.052	.020	****																
5	.217	.166	.267	.241	****															
6	.068	.051	.166	.118	.052	****														
7	.178	.344	.252	.207	.321	.272	****													
8	.045	.149	.094	.074	.238	.139	.028	****												
9	.031	.162	.028	.072	.351	.218	.229	.101	****											
10	.006	.062	.051	.020	.329	.137	.260	.123	.090	****										
11	.040	.133	.069	.063	.320	.156	.143	.040	.091	.023	****									
12	.000	.046	.022	.000	.266	.108	.179	.063	.049	.000	.033	****								
13	.029	.050	.068	.045	.181	.048	.163	.011	.121	.058	.015	.045	****							
14	.071	.172	.135	.102	.231	.126	.021	.000	.144	.106	.021	.074	.023	****						
15	.008	.103	.027	.043	.375	.171	.251	.090	.031	.020	.022	.018	.052	.111	****					
16	.161	.328	.131	.188	.394	.351	.250	.199	.046	.196	.177	.157	.252	.205	.167	****				
17	.052	.138	.104	.076	.275	.132	.075	.000	.128	.058	.000	.048	.000	.000	.069	.209	****			
18	.000	.035	.022	.028	.291	.112	.296	.093	.044	.049	.085	.020	.042	.154	.013	.217	.118	****		
19	.004	.059	.023	.036	.285	.124	.257	.122	.060	.005	.032	.011	.053	.116	.005	.173	.083	.028	****	
20	.026	.140	.031	.045	.407	.218	.290	.137	.030	.043	.064	.029	.109	.165	.000	.158	.129	.027	.016	****
Ď	.051	.012	.084	.075	.274	.146	.211	.092	.107	.086	.080	.061	.072	.104	.083	.208	.089	.089	.079	.109
G	5	5	4	3	5	5	5	4	4	2	5	5	5	3	3	3	5	5	5	3
H	.821	.860	.751	.587	1.167	.976	.375	.557	.406	.448	.125	.613	.890	.531	.293	.418	.531	.808	.696	.363

Table 31: -Allele frequencies in twenty *ex situ* conserved populations

	POPULATIONS																			
Locus	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AAT-2																				
(N)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
A	.200	.000	.000	.200	.200	.000	.000	.400	.300	.000	.100	.000	.000	.400	.000	.400	.000	.200	.200	.200
B	.800	.800	1.00	.600	.800	.800	.600	.200	.500	1.00	.700	1.00	1.00	.600	1.00	.600	1.00	.800	.800	.800
C	.000	.200	.000	.200	.000	.200	.400	.400	.200	.000	.200	.000	.000	.000	.000	.000	.000	.000	.000	.000
LAP-2																				
(N)	5	4	5	5	5	5	5	5	5	3	5	5	5	5	5	5	5	5	5	5
A	.200	.125	.000	.200	.000	.200	.100	.200	.000	.667	.200	.300	.500	.600	.000	.000	.000	.000	.200	.100
B	.700	.750	1.00	.800	1.00	.600	.800	.800	1.00	.333	.700	.600	.200	.200	.700	1.00	.900	.700	.700	.900
C	.000	.125	.000	.000	.000	.200	.100	.000	.000	.000	.100	.100	.000	.100	.300	.000	.100	.300	.100	.000
D	.100	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.300	.100	.000	.000	.000	.000	.000	.000
EST-1																				
(N)	5	4	5	5	5	5	5	5	5	5	5	5	5	4	4	5	5	5	5	5
A	.000	.375	.000	.200	.000	.000	.000	.000	.000	.000	.000	.100	.000	.000	.000	.100	.400	.000	.000	.000
B	.200	.000	.000	.100	.000	.100	.000	.000	.000	.100	.000	.000	.000	.000	.000	.400	.100	.000	.100	.500
C	.200	.500	.400	.600	1.00	.300	.800	.600	.800	.800	.900	.900	.200	1.00	.875	.500	.400	.714	.400	.300
D	.500	.000	.400	.000	.000	.100	.200	.000	.000	.000	.000	.000	.700	.000	.125	.000	.000	.000	.100	.200
E	.000	.000	.000	.100	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.100	.000	.000	.000
F	.100	.125	.100	.000	.000	.500	.000	.400	.200	.100	.100	.000	.100	.000	.000	.000	.000	.000	.100	.000
G	.000	.000	.100	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.286	.300	.000
EST-3																				
(N)	5	4	5	5	5	5	5	5	5	5	4	5	5	5	4	5	5	5	5	5
A	.000	.000	.100	.000	.000	.000	.200	.000	.000	.000	.000	.000	.000	.000	.125	.000	.100	.000	.200	.000
B	.900	.750	.800	1.00	.800	1.00	.600	1.00	1.00	1.00	1.00	1.00	.800	.500	.750	.500	.500	.800	.800	.700
C	.100	.250	.100	.000	.200	.000	.200	.000	.000	.000	.000	.000	.200	.500	.125	.200	.200	.200	.000	.300
D	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.300	.200	.000	.000	.000

Table 32: - Matrix of distance coefficients (Nei, 1978 unbiased minimum distance) for twenty *ex situ* conserved populations

Population	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1 (1E)	*****																			
2 (2E)	.034	*****																		
3 (4E)	.006	.023	*****																	
4 (8E)	.032	.000	.048	*****																
5 (9E)	.106	.035	.057	.028	*****															
6 (11E)	.019	.012	.047	.029	.115	*****														
7 (12E)	.069	.002	.045	.016	.025	.068	*****													
8 (13E)	.100	.068	.141	.017	.101	.054	.059	*****												
9 (14E)	.084	.037	.071	.000	.016	.063	.028	.004	*****											
10 (16E)	.097	.071	.131	.061	.114	.067	.107	.156	.132	*****										
11 (17E)	.072	.013	.066	.000	.013	.036	.009	.037	.002	.034	*****									
12 (18E)	.085	.025	.071	.022	.036	.061	.054	.130	.064	.006	.000	*****								
13 (19E)	.028	.121	.109	.158	.247	.094	.162	.251	.255	.099	.170	.143	*****							
14 (21E)	.176	.113	.232	.126	.129	.187	.100	.168	.173	.078	.098	.106	.171	*****						
15 (22E)	.074	.013	.032	.041	.013	.065	.013	.144	.059	.068	.010	.006	.151	.115	*****					
16 (23E)	.064	.040	.073	.039	.053	.113	.056	.097	.056	.184	.086	.127	.237	.157	.085	*****				
17 (24E)	.067	.000	.030	.049	.068	.083	.053	.177	.106	.145	.089	.079	.172	.190	.038	.026	*****			
18 (25E)	.060	.005	.040	.018	.015	.053	.021	.091	.034	.083	.009	.025	.163	.095	.000	.050	.043	*****		
19 (27E)	.000	.003	.008	.002	.053	.009	.029	.067	.042	.057	.022	.035	.093	.123	.023	.039	.031	.000	*****	
20 (29E)	.000	.026	.025	.036	.072	.060	.058	.121	.081	.133	.083	.101	.129	.169	.068	.000	.030	.048	.013	*****
Ď	.062	.034	.067	.038	.069	.065	.051	.104	.069	.096	.045	.062	.155	.142	.054	.083	.078	.045	.034	.066
G	5	5	4	5	3	5	5	5	5	4	4	4	5	4	5	4	5	5	5	4
H	.821	1.055	.458	.557	.293	.626	.768	.557	.501	.626	.725	.363	.739	.626	.713	.462	.696	.656	.916	.587

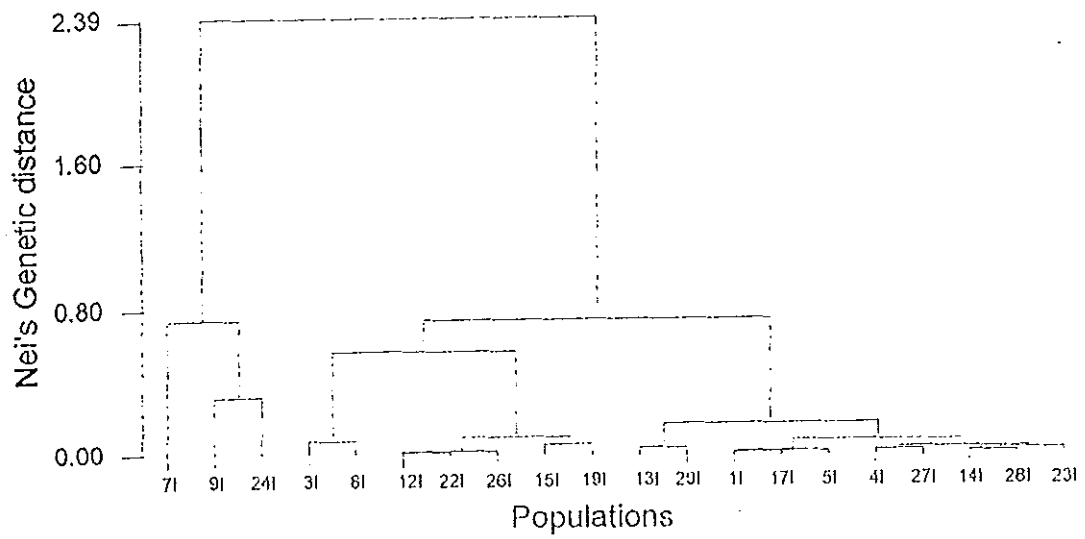

Figure 15: -Dendrogram summarizing the relationship between the twenty *in situ* conserved populations. Genetic distance values were calculated from Aspartate amino trasferase, leucine amino peptidase and a-esterase genotype frequency distribution using Nei's logic.

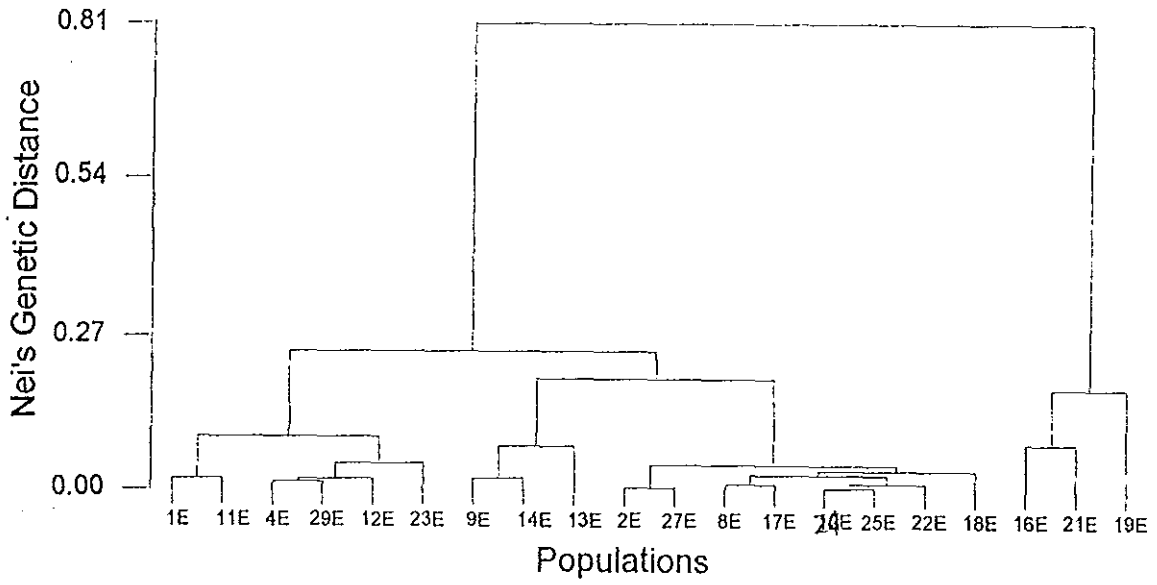

Figure 16: -Dendrogram summarizing the relationship between the twenty *ex situ* conserved populations. Genetic distance values were calculated from Aspartate amino trasferase, leucine amino peptidase and a-esterase genotype frequency distribution using Nei's logic.

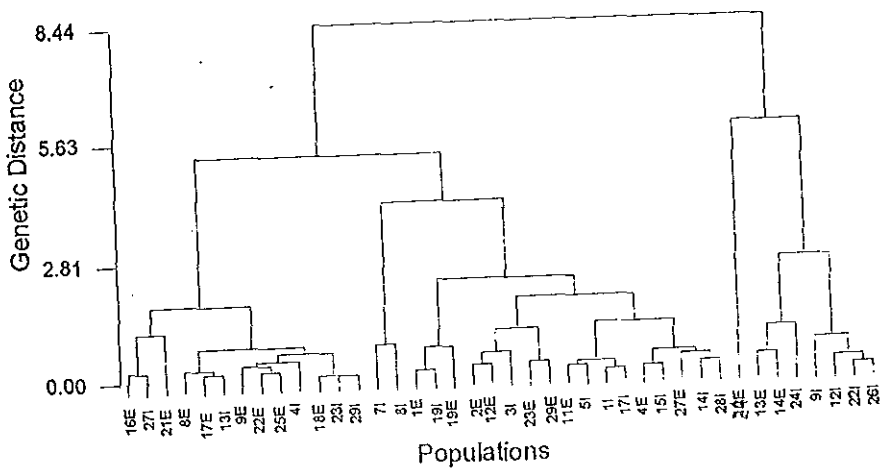

Figure 17: -Dendrogram summarizing the relationship between the twenty *in situ* conserved and the twenty *ex situ* conserved populations. The dendrogram is constructed from allelic frequencies of ATT-2 locus, LAP-2 locus and EST-1and EST-2 locl.

Table 33: - Mean gene frequencies in *in situ* and *ex situ* conserved *Guizotia abyssinica* and the lowest and the highest gene frequency value per population at AAT-2 Loci, Alleles; Allele A, Allele B and Allele C.

No. popn	No. individuals	Group	AAT-2A Frequencies			AAT-2B Frequencies			AAT-2C Frequencies		
			Lowest	Highest	mean	Lowest	highest	mean	Lowest	highest	mean
20	99	*In situ*	0.000	0.800	0.085	0.000	1.000	0.703	0.000	1.000	0.213
20	100	*Ex situ*	0.000	0.400	0.140	0.200	1.000	0.770	0.000	0.400	0.090

Table 34- Mean gene frequencies in *in situ* and *ex situ* conserved *Guizotia abyssinica* and the lowest and the highest gene frequency value per population at LAP-2 locus; Allele A, Allele B, Allele C and Allele D

No. popn	No. indiv	Group	LAP-2A Frequencies			LAP-2B Frequencies			LAP-2C Frequencies			LAP-2D Frequencies		
			Lowest	highest	mean	Lowest	highest	mean	Lowest	highest	mean	Lowest	highest	mean
20	99	*In situ*	0.000	0.400	0.140	0.500	1.000	0.740	0.000	0.400	0.085	0.000	0.400	0.035
20	97	*Ex situ*	0.000	0.667	0.180	0.200	1.000	0.719	0.000	0.300	0.076	0.000	0.000	0.025

Table 35: - Mean gene frequencies in *in situ* and *ex situ* conserved *Guizotia abyssinica* and the lowest and the highest gene frequency value per population at Est-3 locus; Allele A, Allele B, Allele C and Allele D

No. popn	No. indiv	Group	EST-3A Frequencies			EST-3B Frequencies			EST-3C Frequencies			EST-3D Frequencies		
			Lowest	highest	mean	Lowest	highest	mean	Lowest	highest	mean	Lowest	highest	mean
20	97	*In situ*	0.000	0.250	0.024	0.400	1.000	0.870	0.000	0.400	0.081	0.000	0.200	0.025
20	97	*Ex situ*	0.000	0.200	0.036	0.500	1.000	0.810	0.000	0.500	0.129	0.000	0.300	0.025

Table 36: - Mean gene frequencies in *in situ and ex situ* conserved *Guizotia abyssinica* and the lowest and the highest gene frequency value per population at EST-1 locus; Allele A, Allele B, Allele C, Allele D, Allele E Allele F and Allele G

Frequencies		Group	
		In situ	*Ex situ*
EST-1A	Lowest	0.000	0.000
	Highest	0.200	0.400
	mean	0.015	0.059
EST-1B	Lowest	0.000	0.000
	Highest	1.000	0.500
	mean	0.134	0.080
EST-1C	Lowest	0.000	0.200
	Highest	1.000	1.000
	mean	0.538	0.610
EST-1D	Lowest	0.000	0.000
	Highest	0.600	0.700
	mean	0.171	0.116
EST-1E	Lowest	0.000	0.000
	Highest	0.100	0.100
	mean	0.005	0.010
EST-1F	Lowest	0.000	0.000
	Highest	0.400	0.500
	mean	0.110	0.091
EST-1G	Lowest	0.000	0.000
	Highest	0.250	0.300
	mean	0.028	0.034
Number of populations		20	20
Number of individuals		90	97

5.3.2. GENETIC DISTANCES BETWEEN POPULATIONS

In the presently studied *in situ* populations, from genetic distance computations based on Nei (1978) unbiased minimum distance of the four loci studied (Table 27) it is apparent that the mean value of D ranges from 0.051 to 0.274; the lowest being the mean value of genetic distance of population 1I, and the highest being the mean value of genetic distance of population 7I. The highest absolute value of D is 0.407 (D value between population 7I and 29I) and the lowest value is 0.00 recorded in 10 population pairs (Table 30). A dendrogram based on these values unbiased genetic distances is shown in Fig. 15.

In *ex situ* conserved populations the distance values were computed based on Nei (1978) unbiased minimum distance (Table 32). This analysis revealed that the mean value of D ranges from 0.034 to 0.155; the lowest being the mean value of genetic distance of population 2E and 27E, and the highest being the mean value of genetic distance of population 19E. The highest absolute value of D was 0.255 (D value between population 14E and 19E) and the lowest value was 0.00 recorded in five population pairs. A dendrogram based on Nei's (1978) unbiased minimum distances are shown in Fig. 16. Fig. 17 is a dendrogram constructed based on allelic frequencies of the 20 *in situ* conserved populations and 20 *ex situ* conserved populations pooled up.

Table 37: - Estimates of Shannon's diversity index (H; SHANNON and WEAVER, 1949) at four isozyme loci within populations of *Guizotia abyssinica*, comparing two different sample sizes.

Popn	Sample size	H				
		AAT-2	LAP-2	EST-1	EST-3	MEAN
13I	20	0.687	1.030	0.423	0.325	0.616
	5	0.673	0.950	0.000	0.000	0.406
15I	20	0.518	0.518	1.446	0.871	0.748
	5	0.500	0.000	0.000	0.000	0.125
17I	20	0.802	1.752	0.802	0.708	1.016
	5	0.500	0.950	0.500	0.500	0.613
26I	20	0.802	2.129	1.144	0.325	1.100
	5	0.673	0.500	0.950	0.000	0.531
8E	20	0.518	0.914	1.333	0.000	0.691
	5	0.673	0.500	1.055	0.000	0.557
11E	20	0.613	1.175	1.094	1.165	1.012
	5	1.055	0.673	0.500	0.000	0.557
12E	20	0.198	0.746	1.472	0.394	0.703
	5	1.332	0.000	0.673	0.000	0.501
19	20	0.802	1.102	1.723	1.765	1.348
	5	0.000	1.332	0.950	0.673	0.739
Mean	20	0.618	1.171	1.180	0.694	0.904
	5	0.676	0.613	0.579	0.147	0.504

Table 38: -SHANNON'S diversity index partitioned between and within Populations of *Guizotia abyssinica* for eight populations, comparing two different sample sizes.

Locus	Sample size	H_{avg}	H_{sp}	H_{avg}/H_{sp}	$H_{sp}-H_{avg}/H_{sp}$
AAT-2	20	0.618	0.766	0.807	0.193
	5	0.676	0.768	0.880	0.120
LAP-2	20	1.171	1.532	0.764	0.239
	5	0.613	1.225	0.500	0.500
EST-1	20	1.180	1.845	0.640	0.360
	5	0.579	1.852	0.313	0.687
EST-2	20	0.694	1.052	0.660	0.340
	5	0.147	0.461	0.319	0.681
Mean	20	0.916	1.299	0.705	0.295
	5	0.504	1.077	0.468	0.532

Table 39: - Comparison of Nei's genetic distances (1978 unbiased estimates) between paired populations with different sample sizes

In situ			*Ex situ*		
Population pair	Sample size		Population pair	Sample size	
	5	20		5	20
13I/15I	0.010	0.091	8E/11E	0.050	0.029
13I/26I	0.051	0.049	8E/12E	0.001	0.016
13I/26I	0.019	0.128	8E/19E	0.128	0.158
15I/17I	0.063	0.033	11E/12E	0.056	0.068
15I/26I	0.041	0.000	11E/19E	0.052	0.094
17I/26I	0.049	0.048	12E/19E	0.149	0.162
Mean	0.039	0.058	Mean	0.073	0.088

5.3.3. GENETIC DIVERSITY ESTIMATES BASED ON TWO DIFFERENT SAMPLE SIZES

Based on the results given on Table 39, the mean genetic distance between populations was higher with sample size 20 than sample size 5. The mean genetic distance revealed using sample size 5 was 0.039 and 0.073, while it was 0.058 and 0.088 for sample size 20, for *in situ* and *ex situ* populations, respectively. The mean Shannon's diversity index overall the eight populations (four *in situ* and four *ex situ*) was higher for sample size 20 as compared to sample size 5, for all polymorphic loci except for AAT-2. The mean Shannon's diversity index was 0.618, 1.171, 1.18 and 0.694 (for n=20), while it was 0.676, 0.613, 0.579 and 0.147 (for n=5), for AAT-2, LAP-2, EST-1 and EST-3, respectively (Table 37). The Shannon's diversity index partitioned within and between populations revealed larger within population

diversity for sample size 20, which accounted for 70.5% of the total diversity, as compared to sample size 5, which accounted for 46.8% of the total variation (Table 38). The mean Shannon's diversity index overall loci and populations was still higher for sample size 20 than sample 5.

5.3.4.ESTIMATES OF VARIABILITY MEASURES

The level of variation at the four polymorphic loci identified in both *in situ* and *ex situ* conserved *Guizotia abyssinica* was assessed on the bases of the average number of alleles per locus (A), the observed mean heterozygosity (H_o), the expected mean heterozygosity (H_e) assuming random mating and the percentage of polymorphic loci (P) (Table 40).

In *in situ* populations, all four loci were polymorphic for seven of the twenty populations, while two populations (population 24I and 29I) show polymorphism for only one locus. The highest mean number of alleles per locus was recorded for population from Haik (3I), while the highest mean observed heterozygosity was for another population from the same area (19I). The least variable population for all criteria was population from area between Dessie and Kombolcha (24I), which was characterized by mean number of alleles, percentage of polymorphic loci and observed heterozygosity of 1.3, 1.25% and 0.00, respectively.

In the case of *ex situ* conserved populations, the maximum mean number of alleles per locus was 2.8, which was recorded in population 1E and 24E, while the least was 1.5, recorded in population 9E. Unlike *in situ*, at least two of the four loci were polymorphic and in six populations, all four loci were polymorphic. The highest mean heterozygosity was in

population 24E (H_o= 0.5), which was greater than the expected heterozygosity under Hardy-Weinberg assumption (H_e= 0.417).

Table 40: - Genetic variability estimates for all populations surveyed (20 *in situ* and 20 *ex situ* conserved populations). Statistics are based on 4 polymorphic loci (standard error in parentheses). A (Mean number of alleles per locus), P (%age of loci polymorphic), H_o (observed mean heterozygosity) and H_e (expected heterozygosity)

Population	A	P*	Ho	He**
1I	2.3(.3)	100	.37(.177)	.446(.060)
3I	3.3(.9)	75	.450(.206)	.556(.191)
4I	2.8(.3)	100	.200(.082)	.439(.069)
5I	2.0(.0)	100	.050(.050)	.406(.080)
7I	2.5(.5)	75	.250(.096)	.522(.175)
8I	2.5(.3)	100	.383(.164)	.435(.058)
9I	1.8(.5)	50	.300(.238)	.211(.152)
12I	2.3(.3)	100	.450(.222)	.472(.092)
13I	1.5(.3)	50	.050(.050)	.250(.145)
14I	1.8(.5)	50	.300(.238)	.220(.160)
15I	1.5(.3)	50	.250(.250)	.228(.138)
17I	2.3(.3)	100	.350(.171)	.367(.068)
19I	2.8(.5)	100	.463(.217)	.490(.113)
22I	2.3(.6)	75	.300(.238)	.361(.160)
23I	1.5(.3)	50	.100(.100)	.178(.103)
24I	1.3(.3)	25	.000(.000)	.089(.089)
26I	2.0(.4)	75	.250(.189)	.333(.141)
27I	2.5(.6)	75	.200(.115)	.402(.141)
28I	2.0(.4)	75	.300(.159)	.264(.126)
29I	1.5(.5)	25	.100(.100)	.094(.094)
1E	2.8(.5)	100	.3(.129)	.45 (.114)
2E	2.5(.3)	100	.375(.125)	.482(.069)
4E	2.3(.8)	50	.150(.096)	.278(.176)
8E	2.5(.6)	75	.15(.15)	.406(.15)
9E	1.5(.3)	50	.1(.1)	.178(.103)
11E	2.5(.6)	75	.3(.191)	.422(.16)
12E	2.5(.3)	100	.2(.115)	.472(.064)
13E	2(.4)	75	.3(.191)	.4(.152)
14E	1.8(.5)	50	.15(.096)	.261(.165)
16E	1.8(.5)	50	.1(.1)	.228(.135)
17E	2.3(.5)	75	.2(.082)	.306(.126)
18E	1.8(.5)	50	.25(.189)	.2(.141)
19E	2.3(.5)	75	.2(.082)	.389(.146)
21E	2.3(.6)	75	.4(.245)	.433(.146)
22E	2(.4)	75	.175(.06)	.295(.111)
23E	2.3(.5)	75	.5(.289)	.467(.159)
24E	2.8(.8)	75	.5(.238)	.417(.187)
25E	2.0(.0)	100	.193(.135)	.404(.029)
27E	3.0(.7)	100	.3(.173)	.506(.105)
29E	2.3(.3)	100	.45(.222)	.428(.103)

* A locus is considered polymorphic when more than one alleles were detected, ** Nie (1978) unbiased estimates

5.3.5.ESTIMATES OF GENETIC DIVERSITY

In *in situ* conserved populations, the mean Shannon's diversity index overall loci ranges from 0.125 (population 15I) to 1.167 (population 7I), for *in situ* group (Table 41), while it ranges from 0.293 (Population 9E) to 1.055 (population 2E), for *ex situ* conserved populations (Table 43). In the case of *in situ* group, the highest mean Shannon diversity index overall populations was recorded for LAP-2 locus ($\hat{H}$= 0.827) followed by EST-1 ($\hat{H}$= 0.7351) and AAT-2 ($\hat{H}$=0.449), while the least was for EST-3 ($\hat{H}$= 0.440). For *ex situ* group, the highest mean Shannon diversity index overall populations was recorded for EST-1 locus ($\hat{H}$= 0.854) followed by LAP-2 ($\hat{H}$' = 0.719) and AAT-2 ($\hat{H}$' =0.495), while the least was for EST-3 ($\hat{H}$= 0.485). The mean diversity index overall loci and populations was 0.613 and 0.637 for *in situ* populations and *ex situ* populations, respectively. When the *in situ* populations and *ex situ* populations are pooled up and compared, the within groups and between groups Shannon diversity estimates revealed were 0.992 and 0.08, respectively (Table 46).

A comparison of Wright's F-statistics (Wright, 1951) for all twenty *in situ* and twenty *ex situ* conserved populations are given on Table 47. The mean value of F(IS) overall loci suggests that generally there is substantial deviation from random mating within populations for both *in situ* (0.178) and *ex situ* (0.205) conserved populations. The mean value of F(ST) indicates a moderate level of differentiation between populations for both *in situ* (0.313) and *ex situ* (0.237) conserved populations. The highest differentiation for *in situ* populations is at AAT-2 locus (0.428), while it was at EST-1 locus for *ex situ* populations (0.276). The total mean diversity F(IT) was 0.435 and 0.393 for *in situ* and *ex situ* conserved populations, respectively.

Table 41: - Estimates of Shannon's diversity index (H; SHANNON and WEAVER, 1949) at four isozyme loci within twenty *in situ* conserved populations of *Guizotia abyssinica* (n=5)

	H				
Populations	AAT-2	LAP-2	EST-1	EST-3	MEAN
1I	0.500	0.950	1.332	0.500	0.821
3I	0.000	1.332	1.609	0.500	0.860
4I	0.500	1.055	0.500	0.950	0.751
5I	0.500	0.673	0.673	0.500	0.587
7I	1.332	1.332	0.673	1.332	1.167
8I	0.950	0.950	1.055	0.950	0.976
9I	0.500	0.500	0.500	0.000	0.375
12I	0.673	1.055	0.000	0.500	0.557
13I	0.673	0.950	0.000	0.000	0.406
14I	0.000	0.500	0.950	0.500	0.488
15I	0.500	0.000	0.000	0.000	0.125
17I	0.500	0.950	0.500	0.500	0.613
19I	0.500	1.332	1.055	0.673	0.890
22I	0.673	0.500	0.950	0.000	0.531
23I	0.000	0.673	0.500	0.000	0.293
24I	0.500	0.500	0.673	0.000	0.418
26I	0.673	0.500	0.950	0.000	0.531
27I	0.000	1.332	0.950	0.950	0.808
28I	0.000	0.500	1.332	0.950	0.696
29I	0.000	0.950	0.500	0.000	0.363
Mean	0.449	0.827	0.735	0.440	0.613

n=sample size

Table 42: -SHANNON'S diversity index partitioned between and within twenty *in situ* conserved populations of *Guizotia abyssinica* (n=5)

Locus	H_{avg}	H_{sp}	H_{avg}/H_{sp}	$H_{sp}-H_{avg}/H_{sp}$
AAT-2	0.449	0.878	0.511	0.489
LAP-2	0.827	1.375	0.601	0.399
EST-1	0.735	2.195	0.335	0.665
EST-2	0.440	0.922	0.477	0.523
Mean	0.613	1.343	0.481	0.544

n=sample size

Table 43: - Estimates of Shannon's diversity index (H; SHANNON and WEAVER, 1949) at four isozyme loci within twenty *ex situ* conserved populations of *Guizotia abyssinica* (n=5)

Populations	H				
	AAT-2	LAP-2	EST-1	EST-3	MEAN
1	0.500	0.950	1.332	0.500	0.821
2	0.500	1.055	1.609	1.055	1.055
4	0.000	0.000	1.332	0.500	0.458
8	0.673	0.500	1.055	0.000	0.557
9	0.500	0.000	0.000	0.673	0.293
11	0.500	0.673	1.332	0.000	0.626
12	0.950	0.950	0.500	0.673	0.768
13	1.055	0.673	0.500	0.000	0.557
14	1.332	0.000	0.673	0.000	0.501
16	0.000	1.055	0.950	0.500	0.626
17	0.950	0.950	0.500	0.500	0.725
18	0.000	0.950	0.500	0.000	0.363
19	0.000	1.332	0.950	0.673	0.739
21	0.673	1.332	0.500	0.000	0.626
22	0.000	0.950	0.950	0.950	0.713
23	0.673	0.000	0.500	0.673	0.462
24	0.000	0.500	0.950	1.332	0.696
25	0.600	0.950	0.673	0.500	0.656
27	0.500	1.055	1.609	0.500	0.916
29	0.500	0.500	0.673	0.673	0.587
Mean	0.495	0.719	0.854	0.485	0.637

n=sample size

Table 44: -SHANNON'S diversity index partitioned between and within twenty *ex situ* conserved populations of *Guizotia abyssinica* (n=5)

Locus	H_{avg}	H_{sp}	H_{avg}/H_{sp}	$H_{sp}-H_{avg}/H_{sp}$
AAT-2	0.495	0.769	0.644	0.356
LAP-2	0.719	1.427	0.504	0.496
EST-1	0.854	2.076	0.411	0.589
EST-2	0.485	1.114	0.435	0.565
Mean	0.638	1.347	0.474	0.526

n=sample size

Table 45: - Estimates of Shannon's diversity index (H; SHANNON and WEAVER, 1949) at four isozyme loci within *ex situ* (n=180) and *in situ* (n=180) conserved groups of *Guizotia abyssinica*

Group	H				
	AAT-2	LAP-2	EST-1	EST-3	MEAN
In situ	0.928	1.376	2.138	0.845	1.322
Ex situ	0.719	1.350	2.086	1.294	1.362
Mean	0.824	1.363	2.112	1.070	1.342

n=sample size

Table 46: -SHANNON'S diversity index partitioned between and within *ex situ* and *in situ* conserved populations of *Guizotia abyssinica*

Locus	H_{avg}	H_{sp}	H_{avg}/H_{sp}	$H_{sp}-H_{avg}/H_{sp}$
AAT-2	0.824	0.831	0.992	0.008
LAP-2	1.363	1.340	1.017	-0.017
EST-1	2.112	2.212	0.955	0.045
EST-2	1.070	1.030	1.039	-0.039
Mean	1.342	1.353	0.992	0.008

n=sample size

Table 47: -Summary of F-statistics at all loci for twenty *in situ* conserved populations and twenty *ex situ* conserved populations

Locus	F (IS)		F (IT)		F(ST)	
	In situ	*Ex situ*	*In situ*	*Ex situ*	*In situ*	*Ex situ*
AAT-2	.962	.933	.978	.947	.428	.215
LAP-2	.178	.180	.317	.201	.168	.244
EST-1	-.267	-.104	.198	.201	.367	.276
EST-3	.067	-.077	.256	.116	.203	.179
Mean	.178	.205	.435	.393	.313	.237

Table 48: -Chi-square test for the deviation from Hardy-Weinberg equilibrium

Locus	Chi-square		Df+	
	In situ	*Ex situ*	*In situ*	*Ex situ*
AAT-2	321.3***	345.135***	3	3
LAP-2	70.403***	47.63***	10	10
EST-1	134.104***	198.713***	21	21
EST-3	360.004***	130.354***	10	10

*** Significant at P=0.001, + degree of freedom based on the number of heterozygote observed

Table 49 -Coefficients for heterozygotes deficiency or excess

Locus	Observed heterozygosity		Expected heterozygosity		D*	
	In situ	*Ex situ*	*In situ*	*Ex situ*	*In situ*	*Ex situ*
AAT-2	2	5	72.89	61.31	-0.931	-0.967
LAP-2	55	57	74.57	74.39	-0.236	-0.261
EST-1	67	65	99.80	108.87	-0.349	-0.385
EST-3	37	24	46.68	70.02	-0.486	-0.472

* measures of heterozygotes deficiency or excess.

6.DISCUSSION

6.1.'ETHNOBOTANICAL STUDY

6.1.1. SELECTION CRITERIA AND CONSERVATION STRATEGY OF DIFFERENT OIL CROPS, AND THEIR COMPANIONSHIP WITH SORGHUM AT HOME LEVEL

It is clear that oil crops are the source of edible oil, and oil is always important in the majority of food types prepared from any plant and animal products. In the study area, the amazing companionship of oil crops with sorghum is beyond the usage of oil crops for production of oil. In other words, the strong association of oil crops with sorghum at field level (on-farm) is mainly because of its true association in preparing food varieties. The majority of food prepared by the community in the study area, from sorghum and other cereal crops, incorporate oilseeds prepared in different forms to make it more palatable and to increase the nutritional quality of the food, since oil crops are rich not only in their oil content but also in their protein content (Abebe *et al.*, 1978).

South Welo is rich in crop genetic diversity, particularly S*orghum bicolor* (L.) Moench, and about sixty distinct sorghum landraces are known in the area (Teshome, 1996). This diversity of crop genetic resources is realized through traditional conservation strategies and farming practices. Farmers cultivate and preserve their crops, which are rich in genetic diversity, primarily for their subsistence. The great diversity of sorghum in the area facilitated the diversified use of this crop, and some sort of specialization is also seen

in which different landraces are preferred for different food types in combination with edible oilseeds.

To fulfill the criteria required for each food type, it is very important to cultivate different oil crops. For example, roasted grains (Kolo) are a common food in the daily life of poor farmers of the region. Sorghum landraces, which are preferable for kolo are those that burst open upon roasting (e.g. Mokake and Gorad) and thus, farmers selectively cultivate these landraces for Kolo. Once they decide to cultivate these landraces they also decide to cultivate oil crops, which are best for Kolo. These oil crops are mainly sunflower and safflower, and they cultivate both or either of the two oil crops to fulfill their needs, hence, *in situ* conservation of both sorghum and oil crops. This is not always true, because of both natural and artificial factors.

At field level, the companionship of oil crops and tef is stronger than that of oil crops and sorghum. This strong companionship of oil crops and tef at the field level is not seen at home level. The two major reasons behind this fact are that few food types are prepared from tef and tef is cultivated mainly for market demand. Several food types prepared from sorghum, for example, kinche, kolo, nifro and dimiso are not prepared from tef. Tef is mainly used for injera which is usually eaten with wot and consequently use commercial oil or kibanoog. Secondly, farmers of the study area cultivate tef mainly as a commercial crop and they consume it rarely, especially during special occasions. Thus, farmers are not well practiced on combined use of oil crops and tef and mixed cropping of oil crops in tef fields is to facilitate sorghum consumption.

In some cases because of unfavorable environmental conditions, the cultivated crops might fail to grow, as it has repeatedly happened. Farmers of the study area have good practice of reducing such risks. They maintain some part of their seeds in their store for safety, which is a sort of *ex situ* conservation strategy. According to farmers of the study area, all oil crops included in this research have a good potential to be stored for long period. Seegeler (1983) also supported this idea. Farmers have a very good experience of preserving oil crops at their own stores for continuous cultivation. This good habit of seed preservation has been practiced with ease, because oil crops cultivation does not require separate land preparation, as they most frequently mixed cultivate with cereals. Oil crops are better preserved by farmers than cereals (Table 3), because oil crops are not usually consumed alone, so that farmers have a better patience to preserve it even during period of food shortage.

Cultivation of oil crops in the study area is not only for food values but also for their uses as traditional medicine and cultural practices. For example, "Mewekel" is a widely celebrated cultural practice in which noog and sorghum are always involved. Thus, as described by Brush (1995), this cultural preference is important for genetic diversity of these crops, which is achieved through continuous cultivation. Some use values of oil crops revealed by this study might not be common for other areas, conversely, some use values reported by researchers are not common in the study area. For example, the use of noog oil as a birth control reported by Belayneh (1991) is not a common practice in the study area. On the other hand, the use of sesame leaves as a treatment for "Antako" might not be common in other areas, as it is not reported in any one of the literatures reviewed for this work. Thus, if use values of oil crops restricted to some regions are practiced in the other regions, it might help for future *in situ* conservation of these crops in the area where they have not commonly

cultivated, which helps for adaptation of the crop to wide environmental conditions. This in turn promotes genetic diversity of the species that helps it withstand variable environmental stresses (Bekele, 1985).

Species agromorphological characteristics are the link between farmers and the crop genetic diversity in their field (Jarvis, 2000). This crop genetic diversity might be reflected on agromorphological characters, which helps to identify and select varieties. For example, there are many landraces of sorghum in the study area, which have been categorized by farmers based on their agromorphological characters, agronomic traits and so on (Teshome *et al.*, 1997&1999a). When variation among varieties of the same species is distinct, farmers use these distinct traits for their selection criteria. In other words, when several landraces exist within the species, each landrace might have its own quality to get priority in farmers' selection for some use values. However, unlike sorghum most oil crops are never classified into landraces, which might be due to the absence of distinct morphological and agronomic traits within the species. In cases when such distinct characters exist, they group them into farmers' varieties. For example, because of the presence of distinct seed color they group sunflower into "nech ye ferenj suf" and "tikur ye ferenj suf" as a local name for sunflower with white seeds and black seeds, respectively (Table 2). Similarly, using the number of seeds per lobe of linseed head they group it into double seeded "dirib telba" and single seeded "netela telba" varieties. As summarized in Table 2 *Guizotia abyssinica* is locally known as "noog" without being further classified into landraces. Farmers assert that this is because of the absence of distinct characters to classify them into farmers' varieties. The less prominent morphological differences in noog might be due to its predominant outbreeding nature, as

differences between varieties could be less prominent in cross-pollinated crops than in self-pollinated ones (e.g. Jarvis *et al.*, 2000).

Farmers classify sesame into two, "Nech selit" (White seeded sesame) and "Key selit" (brown seeded sesame), depending on their seed color. However, "Nech selit" is not cultivated in the area. Farmers show a clear preference for brown seeded genotypes, because their planting season coincides with that of sorghum and they have good adaptation and high yield under the existing environmental conditions. In other words, both artificial selection and natural selection work against white seeded sesame varieties. Furthermore, sesame genotypes cultivated in the area were all dehiscent. These genotypes are liable to both pre- and post-harvest loss (Woldemariam, 1993). This dehiscent nature has contributed to the strong companionship of sorghum and sesame as intercrops, because sesame cultivated under the shade of sorghum matures gradually and so allows gradual harvesting, thus, reduces preharvest loss. As far as farmers' knowledge is concerned, the reason why only dehiscent genotypes have been cultivated is not clear, however, it might be due to its threshing ease or due to the absence of indehiscent varieties.

However, depending only on few varieties is disadvantageous because of low diversity among them, which results in low overall fitness to the continuously changing environment and in evolution of varieties that can better withstand environmental catastrophes. In other words, mixed cultivation of different genotypes with better yield might be advantageous to enhance the genetic diversity, because this helps for evolution of better fit varieties through natural hybridization.

6.1.2. DISTRIBUTION OF MAJOR CEREAL CROPS AND THE SIX EDIBLE OIL CROPS

In Ethiopia, especially in the study area, unfavorable environmental conditions for crop cultivation have been repeatedly happened (e.g. Worede *et al.*, 2000). However, farmers of the study area, use different mechanisms to overcome this problem. To reduce the risk of total crop failure, multiple cropping system that has been practiced in the area is advantageous. For example, it was very interesting to mention that 46.23% of tef fields studied at Shewa Robit were intercropped both with sesame and safflower. Furthermore, if the crop planted in one growing season fails, farmers cultivate the same crop or the replacement the next season, which helps for continuous conservation of the species.

One essential point that has to be noted here is that farmers could not cultivate oil crops on separate plots because of land shortage, and they give priority to major cereal crops, which are the staples. Farmers' strategy to overcome this problem is through developing beneficial and effective agricultural practices. Multiple cropping system has been a solution to this problem, as it is a closely adapted system to the prevailing ecological and socio-economic conditions (Steiner, 1982). Multiple cropping system has been the major strategy for *in situ* conservation of oil crops, which contributes to their strong companionship with sorghum and tef.

Agricultural practice of cultivating oil crops in sorghum fields is a widespread phenomenon throughout the study area. All six edible oil crops, covered by this study, were cultivated as a companion of sorghum at least in some of the study sites. The most prevalent type of intercropping in the area is mixed cropping in which both sorghum and oil crops are

broadcasted randomly throughout the plot. Row intercropping is least practiced in the area, and it was only noog that was rarely intercropped with sorghum in rows (strips), especially following adjacent sides of traces within sorghum fields. Intercropping of oil crops and sorghum is a more frequent cropping system in this traditional agricultural system as compared to border cropping.

Noog and sesame are very interesting in that they have almost identical and equal economic importance but show significant difference in cropping patterns. In these multiple cropping systems, noog is frequently border cropped than any other oil crops (Table 12). Why do farmers cultivate noog as border crop more frequently than other oil crops? Some of the various reasons are: (1) noog has good adaptation to marginal and poor soil (Doggott, 1987) and the field does not require intensive land preparation, which might be due to the crop nature to withstand salinity and low oxygen level (Abebe *et al.* 1978). Farmers explain this by saying "ye noog irsha kerker new", which means noog field is marginal and it does not share fertile field used for cultivation of cereal crops. (2) *G. scabra* ssp *schimperi* is a well-known weed in the area, and it is locally called "Mech". Cattle do not enjoy eating "mech" unless there is a serious shortage of animal feed. Similarly, noog plant is not easily attacked by domestic animals, which might be because of its similar morphological appearance with mech (Dagne, 1994) so that it mimics mech, which is supported by farmers; it might also be because of its detastefullness. (3) As a common practice sorghum is mainly planted in April (e.g. Teshome, 1996), while noog is planted during the main rainy season, thus, unless sorghum plants has low seed rate either by natural disaster or purposefully, young seedlings of noog cannot compete the already grown sorghum plants. Thus, farmers prefer planting noog at the border including areas where sorghum plants have been lost. (4) According to

farmers, this crop has a characteristic of suppressing weeds and prevents the introduction of weed to crop fields, which is in agreement with reports of Alemaw and Alemayehu (1992). According to them, this crop is very important as a pioneer weed killer. Personal observation of free spaces near noog plants also supports this idea. The suppressive or preventive action of noog might be either through strong competition or through chemical secretion or both. Some people wrote about noog allelopathic effect on other plants; however, I have not come across even a single scientific publication that deals with allelopathic effect of noog.

Sesame, on the other hand, was strongly associated with sorghum as intercrops, which is farmers' strategy to increase yield per plot and to get variety of crops that are used in their daily life. This strong companionship is because of similar planting season and compatibility of the crops. Both crops are commonly planted in April, so that it is an easy job for farmers to broadcast sesame seeds immediately after they planted sorghum. Based on farmers' knowledge, sorghum and sesame are highly compatible in which net return per plot of land is higher than sole cropping of either sesame or sorghum. Border cropping has no such significant effect, because the crops are planted on separate soil, and hence the chance of using the same resource sequentially or from different depth is less likely.

In Shewa Robit, sesame is cultivated twice a year. Sesame planted in April is almost exclusively intercropped with late maturing sorghum, while sesame planted in the main rainy season (June and July) is almost exclusively intercropped with tef. Personal observation and farmers' knowledge shows that planting sesame during the main rainy season is not a common agricultural practice in the other study sites. After harvesting of tef, sesame sown during the main rainy season in tef fields grows vigorously, become highly branched, and

covers the wide spaces between plants. In tef fields where both safflower and sesame are intercropped, tef is harvested first, which is followed by sesame and finally safflower. This is a typical example of sequential usage of raw materials by intercropping crops, which helps to increase the overall net yield return per plot of land.

Border cropping of Ethiopian mustard is not common both in sorghum and tef fields because, unlike other oil crops, it is cultivated mainly for its young shoots and leaves, which is easily attacked by domestic animals. Thus, farmers usually intercrop it in the middle of tef and sorghum fields to reduce its exposure to attack of domestic animals. However, when grown within sorghum, light might be lacking, and thus affects its production capacity (Woldemariam *et al.*, 1971; cited in Seegeler, 1983). This might be true because, as it had been seen during the study, plants intercropped with tef have many branches with many capsules as compared to those intercopped with sorghum.

Safflower was grown in higher frequency in areas where tef is dominantly cultivated. It is less frequently intercropped with sorghum (only 10.4% of sorghum fields with oil crops were intercropped with safflower). On the other hand, this oil crop was intercropped in tef fields about three folds of that of sorghum (33.33%) in the same site. This is because: (1) safflower and tef have the same planting season (the main rainy season), while sorghum is more frequently planted in April, and (2) this plant cannot withstand the shadowing effect of sorghum because it grows well in direct sunlight (Purseglove, 1968). Farmers' practice of intercropping of safflower and tef is because safflower has an advantage of preventing lodging of tef as it supports teff by its stiff structure (Seegeler, 1983). Furthermore, as stated by Seegeler (1983), because of its slow initial growth habit it is extremely susceptible to weed

competition after emergence. Thus, combination of these two crops is logical, because both tef and safflower develop slowly at first and do not compete too strongly with each other, which helps to reduce weed competition. This shows that farmers of the study area have accumulated knowledge on specific combination of crops at field level, which is also reported by Teshome (1996).

Sunflower has not been given priority in the area. Even in cases of its occurrence, only few plants were seen scattered throughout the field or forms single to few lines at the borders of the sorghum fields. Sunflower and safflower have almost similar use values, and even have identical local name, "Suf". They identify them by calling them "ye habesha suf" for safflower and "ye ferenj suf" for sunflower, which could be translated as local and introduced, respectively. However, farmers usually prefer safflower to sunflower, because of its long cultivation history in the area. Even in areas where safflower was not cultivated farmers give priority for safflower to buy for consumption. It might be safe to conclude that the long cultivation history of safflower in the area has suppressed the cultivation of sunflower. However, sunflower was unique in its occurrence in gardens, usually intercropped with maize, especially at Laygnaw Ataye and Haik. This might be due to its smart appearance and beautiful flower rather than its importance as food.

Both sorghum and tef have shown very low companionship with linseed. Generally, it might be safe to conclude that farmers preferred cultivating linseed as a sole crop rather than combined cropping, including Haik, where linseed was cultivated frequently. As one moves up the hill starting from lake "Haik" the frequency of linseed farms increased significantly, because linseed is usually cultivated at higher altitudes as compared to other oil crops (e.g.

Alemaw and Alemayehu, 1992). The least companionship observed between linseed and sorghum at field level (Table 9) might be the difference in optimum altitudinal ranges in which these two crops are cultivated and also as explained by farmers, linseed can not tolerate the competition it faces from sorghum including shadowing effect.

Correlation analysis for the proportion of sorghum and oil crops within the field revealed that most of them did not show the expected negative correlation. In other words, the overall results of this analysis and information generated from farmers themselves revealed that although there were strong intercropping practices of oil crops and cereals (especially sorghum and tef) throughout the study area, most farmers do not intercrop proportionally, and they simply and randomly broadcast both crops. In other words, intercropping was a random practice in which a farmer did not plan to sow predictable level of oil crops in predictable level of sorghum, or environmental factors might change the ratio existed at early growth stage at maturity, if we think that there was separate environmental stresses on the two crop type.

Such random mixed cultivation of crops imposes a difficulty to know the proper ratio of mixed crops, which give a high yield. Several research works from different parts of the world indicated that different ratios of mixed crops give different yields (e.g. Tiwari *et al.* 1994). Generally, an increase in number of sorghum per given area did not show a significant decrease in number of oil crop within that area and vice versa.

Combination of oil crops in the case of multiple cropping has shown difference among tef and sorghum fields. For example, combined cultivation of sesame + safflower + Ethiopian

mustard, sesame + noog + safflower, noog + Ethiopian mustard + linseed, were not recorded in sorghum fields, but in tef fields, on the other hand, combined cultivation of noog + Ethiopian mustard + sesame, noog + sesame + linseed, sesame + Ethiopian mustard + sunflower were recorded in sorghum fields but not in tef fields. However, combination of noog + sunflower + Ethiopian mustard were recorded in both fields. As it has been discussed in this section, these results clearly indicate that safflower has stronger companionship with tef than with sorghum, while sesame had stronger companionship with sorghum than with tef. Generally, such results are evidence for farmers' intentional work, about which oil crops are matched with which cereal crop.

6.2. AGROMORPHOLOGICAL CHARACTERS

SESAME

Estimates of broad sense heritability and genotypic coefficient of variation indicated the importance of seed yield per plant, number of capsules per plant and number of branches per plant in the selection of genotypes with high yield potential (Suburta and Maity, 1997). Number of capsules per plant and number of seeds per capsule are the direct contributors of seed yield per plant. In this study, the relationship between number of branches per plant and number of capsules per plant was not significant, although it is positive. On the other hand, plant height and number of branches per plant was significantly and positively correlated. The interesting result of this analysis is the significant negative correlation between plant height and number of capsules per plant. This might be due to low number of capsules per branch in taller plants as compared to shorter plants. According to this study number of branches is not important in selection of genotypes with higher yield potential because plants with large

number of branches posses shorter capsules with relatively lower number of seeds per capsule, which is contrasting with the results obtained by Suburta and Maity (1997). According to this study, it seems that shorter plants with low number of branches give high yield, because this group will produce high number of capsules with larger number of seeds per capsule.

Capsule length, number of capsule per plant and number of seeds per capsule are the important traits for high yield, for sesame genotypes found in the study area. These characters have high heritability values (e.g. Patil and Sheriff, 1996). Thus, selection for these traits might be important for improving yield. This traits have shown high variability as revealed by analysis of variance with the range of 26 –34 mm, 68-96, and 47-938 for capsule length, number of seeds per capsule and number of capsules per plant (Table 17), which is in agreement with the work of Manivannin and Nadarajan (1996). Manivannin and Nadarajan (1996) reported that plant height was the major contributor of genetic divergence among the genotypes, however, sesame plants from both Shewa Robit and Bati did not show significant variation.

NOOG

Results of correlation analysis revealed that unlike sesame, plant height and number of primary branches was positively and significantly correlated with number of heads per plant in noog. Generally, plants with larger number of heads per plant were characterized by tall size, large leaves and many primary branches. Number of branches per plant, and number of heads per plant are the main traits that determine yield (e.g. Mathur and Gupta, 1995; Borole

and Patil, 1997). The highly significant positive phenotypic correlation coefficients among the numbers of branches and the number of heads per plant indicates that emphasis should be given to these two traits when selecting individual plants in the varietal renovation programs of the noog population, under favorable environmental conditions. According to Hedge *et al.*, (1999,2000), these traits show strong genotype–environment interaction (GxE). Significant variation in number of primary branches, number of heads per plant, leaf length, leaf width and head size between Haik and Borkena drainage might be due to this strong genotype-environment interactions. The system of continuous cultivation of noog by individual farmers is mainly through preserving seeds for next generation and at the second level through exchanging seeds with neighbors and relatives in the nearby areas (Table 3). Thus, it seems as if gene flow between distant areas (e.g. Haik and Borkena drainage) is low, which contrbutes to the formation of separate gene pools. Furthermore, variation in environmental conditions (rainfall, altitude, temperature and soil) contributes to this variation.

Less variation within area might be due to gene flow by seed exchange between farmers and cross-pollinating nature of the plant (because it is self incompatible) and relatively similar environmental conditions. It might be interesting to note the huge differences in number of heads per plant, which ranges from 36 to 3910 (Table, 19), under these diverse environmental conditions. This huge difference might indicate the presence of genotypes with potential for high yield. Thus, selecting such genotypes using the currently available techniques for self-incompatible plants such as bagging method to develop self-compatibility mechanism (Sinha *et al.*, 1993a), might be reasonable to increase the low yield of *Guizotia abyssinica* claimed by farmers and researchers. The significant variation in head size revealed by analysis of variance indicate the potential for improving yield through selecting genotypes with big head

size. Because genotypes with large head result in larger number of seeds/head hence high yield (Nemomissa *et al.*, 1998).

SAFFLOWER

Results of correlation analysis have shown that number of capitulum per plant did not show positive correlation with any of the eight characters. Seed yield has strong positive phenotypic and genotypic correlation with number of capitulum per plant (Sharma *et al.*, 1998; Pandya *et al.*, 1998). In other words, number of capitulum per plant is one of the traits that show maximum direct effect on yield, suggesting that emphasis should be given on this trait while selecting to improve yield. According to Pandya *et al.* (1998), this trait shows high heritability indicating that it is mainly determined genetically. Although there was no significant variation in number of capitulum per plant between populations, as revealed by analysis of variance (Table 18), it ranges between 64-219 within that narrow area and ranges from 86-219 within populations (farms). This indicates that there is good chance to improve the yield per given area through successive selection of genotypes with large number of capitulum per plant.

6.3. ISOZYME ANALYSIS

The genetic variability of a population is usually measured by the average heterozygosity per locus, while the gene differences between two populations may be measured by the genetic distance (Nei, 1972). Estimating variance of heterozygosity depends on various assumptions, which include (Nei and Roychoudhury, 1974; Nei, 1978): (1) Random mating populations (2)

the genotype frequencies are in Hardy-Weinberg proportions (3) there is no dominance and all heterozygotes are identifiable (4) the genes are sampled randomly (5) the population size is much larger than the sample size.

However, in the present study some assumptions are not fulfilled. In other words, the populations are not random mating, because *Guizotia abyssinica* is self-incompatible and the genotypic frequencies are not expected to be in Hardy-Weinberg proportions. The selection of the enzyme system was not random rather only depend on the availability of materials thus, the genes studied were not randomly selected. Because of these limitations, the estimate of heterozygosity is no longer true. However, it is a good measure of genic variation of the populations, and the value calculated as average heterozygosity may be called heterogeneity index or gene diversity (Nei and Roychoudhury, 1974), which is equal to the probability of non-identity of two randomly chosen genes.

Nei's (1978) estimation of average heterozygosity and genetic distance used for the data analysis applies to any sample size, as long as many loci are used. However, if one wants to study the average heterozygosity and the allele frequency distribution for each locus, large number of individuals and large number of loci are required (Nei, 1978). In the present study, both number of loci and number of individuals studied are small, so that values obtained from this study has their own limitations.

6.3.1. ESTIMATES OF VARIABILITY MEASURES AND GENETIC DIVERSITY

In the presence of limitations discussed above, there is considerable genetic variation within populations of *Guizotia abyssinica* as revealed by analysis of estimates of variability measures and measures of genetic diversity within and between populations. On the average, all populations studied are rich in alleles, which would be useful for conserving germplasm resources and selection programs (Gottlieb, 1975; cited in Bekele, 1983a). It also facilitates selection for high levels of recombination and thus, the ability to generate new and more highly adapted genotypes (Bekele, 1983a).

Nei's measure of genetic distance has been defined in terms of identities of genes (Nei and Roychoudhury, 1974), so that it is affected neither by non-random mating nor by natural selection. The highest mean genetic distance obtained in this analysis was 0.274 (Table 30) for population 7I. This value is low which might be because: (1) the area from which the samples were collected was narrow which might allow high gene flow between populations, (2) the small sample size used, for both *in situ* and *ex situ* conserved populations (Table 39), and (3) few enzyme systems used (few number of loci studied).

The highest mean Shannon's diversity index overall loci was 1.362 (Table 45) for pooled *ex situ* populations, this level of diversity using 4 isozyme loci is relatively higher and it implies that there is high potential of isozyme diversity of Ethiopian noog. Genetically differentiated populations are often suggested as candidates for special management consideration to prevent the loss of unique genetic variants (Leary *et al.*, 1993; cited in Leberg, 1996). Dendrograms given on figure 15 and 16 indicate that some populations [e.g. 71 (Fig. 15) and 19E (Fig. 16)] are genetically distant from the rest, which might need special attention.

The highest between populations' Shannon's diversity index was recorded for Est-1 in *in situ* populations, which was 0.665 (Table 42). The high value recorded at this locus might be because of its large number of alleles.

The higher mean genetic distance values revealed for sample size 20 as compared to sample size 5 might be because of small number of loci studied, which results large sampling error (Nei and Roychoudhury, 1974, Nei, 1978), which might also true for Shannon's diversity index.

6.3.2.COMPARISON OF *IN SITU* AND *EX SITU* CONSERVED POPULATIONS

The results obtained from Shannon diversity index partitioned within and between *in situ* and *ex situ* groups have shown that genetic diversity between the *in situ* and *ex situ* groups is too low, which accounted for only 0.08% of the total genetic diversity (Table 46). Based on the Wright's F- statistics (Table 47), the mean value of F_{IT} overall loci obtained for *in situ* and *ex situ* was 0.435 and 0.393, respectively. The mean Shannon's diversity index overall twenty populations and all enzyme loci were 0.613 (Table 41) and 0.637 (Table 43) for *in situ* and *ex situ*, respectively. When *in situ* populations are pooled as one, its mean Shannon's diversity index was 1.322, while this value was 1.362 for *ex situ* populations (Table 45).

Results presented in the above paragraph and dendrograms constructed using allelic frequencies of both *in situ* and *ex situ* populations (Fig. 17) did not show clear differentiation between these two groups. There are several possible reasons behind this outcome. One of

these reasons might be the short *ex situ* conservation period (16-28 years) and, hence, the currently exisiting genetic variability has been existing before *ex situ* conservation started. For example, population 1E (population from Kombolcha) was conserved *ex situ* since 1973, but its variability estimates were high and greater than some *in situ* conserved populations. In other words, the vast store of genetic variability that has been existing has passed down from earlier generations to the present generations and also maintained for future generations. These results might suggest also the absence of genetic erosion in this species. The sampling error introduced because of small number of loci studied might also contributes to these values.

Significant deviation from Hardy-Weinberg expectations was revealed in both *in situ* and *ex situ* conserved populations (Table 48). As a self-incompatible crop, this deviation is expected because self-incompatibility does not allow free intercrosses. In other words, as an outbreeder the frequency of heterozygotes increased and frequency of homozygotes reduced relative to random mating populations, which affects all loci in the genome (Weaver and Hedrick, 1989). However, the results obtained by this study have shown significant heterozygote deficiency, which is opposite to what normally expected. Although there is no clear-cut answer for this outcome, some possible explanations might be given.

Because of small number of loci studied, the exact test of significance for average heterozygosity is difficult (Nei and Roychoudhury, 1974), thus the significant deviations from Hardy-Weinberg equilibrium revealed (table 48) has limitations. This significant heterozygote deficiency might also be due to the presence of more than one favored alleles (coadaptive alleles) with antagonistic interaction. The fitness value in the presence of two favored alleles

is less than the fitness value in which only one of the favored alleles exists, hence heterozygote disadvantages.

7. CONCLUSION

In this study the companionship of oil crops with sorghum at home and field level were analyzed. Use values and farmers' selection criteria were also assessed and agromorphological traits of oil crops characterized on-farm. Comparison of *in situ* and *ex situ* conserved populations of *Guizotia abyssinica* was made at isozyme level. From the results of these investigations, the following conclusions were made:

- Oil crops show true companionship with sorghum and the wider their use values with sorghum landraces at home the stronger the companionship they show at the field level. Based on the association of oil crops with sorghum at home level, it might be worthy to say that the companionship of these crops depend on the demand of a specific oil crop in sorghum diet and other use values. In this respect, noog and sesame are more frequently associated with sorghum both at home and in the field. These oil crops are more associated with some sorghum landraces in food preparation than with others as seen in the case of Gorad, Mokake etc.
- The companionship of noog with sorghum is significantly as boarder crop, while that of sesame, safflower and Ethiopian mustard are as intercrops.
- The study area is rich in sorghum landraces, which have various use values with some sort of specialization. This sorghum diversity has contributed to *in situ* conservation of various oil crops, because farmers' preferably incorporate different oil crops for different use values of sorghum landraces.
- Unlike sorghum, distinct morphological and agronomic traits are not common in oil crops, and thus, there are few farmers named varieties.

- Noog and sesame have shown significant variation in agromorphological traits, which are directly associated with seed yield. This implies that there is genetic potential in these crops for the improvement of seed yield.
- Farmers' strong preferences for noog and sesame are because of their wide socio-economic importance and their wide adaptation.
- Variation in morphological and agronomic traits of noog reported by various researchers among populations of Ethiopian noog from different regions of the country is also exhibited on *in situ* conserved population of noog from south Welo.
- Isozyme study has revealed significant genetic variation in the three enzyme systems (AAT, LAP and a-EST) for both *in situ* and *ex situ* conserved populations suggesting that the present genetic diversity has been established among and within populations of the species long before *ex situ* conservation started in the country.
- The 19 alleles revealed within the four isozyme loci indicate that this species is highly adapted to the study area and has high potential for the production of genetically diverse and adapted phenotypes, allowing their durability in a changing environment. This also facilitates selection for high level of recombination and, thus, the ability to generate new and more adapted genotypes.
- Although cultivation of noog is not at large scale, the high level of genetic variability revealed in this study implies that the study area is the possible center for diversity of this species, which is achieved through continuous on-farm conservation together with cereal crops, mainly sorghum.

8. RECOMMENDATIONS

- Mixed intercropping is the prominent agricultural practice in the study area, and almost there is no row intercropping practice. However, results of modern researches have shown that row intercropping with appropriate ratios is advantageous for high net return per plot of land. Thus, researches have to be conducted on row intercropping of sorghum and tef with oil crops to determine the ratios of best yield.

- The results of the study have revealed that farmers do not use a fixed proportion of the seeds of cereals and oil crops to be intercropped. Thus, researchers' input is necessary to determine the appropriate proportions of each crop mixed, in order to get a high net return per plot of land.

- Sesame grown in the area is almost completely dehiscent and the genotypes are known to have high pre- and post-harvest loss. Thus, investigation on dehiscent varieties and introduction of indehiscent varieties might be advantageous to reduce preharvest loss of the crop and to increase genetic diversity of the species within the area through hybridization.

- The food types made from mixtures of cereals and oil crops are nutritious and delicious but their use outside the study area is not encouraging as one could see in urban areas. Means for promotion of these food types are beneficial to the society as well as to the conservation of these crops.

- Germplasm collection for *ex situ* conservation in our country is encouraging to maintain genetic material in the state it was collected and to avoid genetic erosion because of environmental stresses. However, to compare the advantages and disadvantages of *in situ* and *ex situ* conservation strategies for each species, germplasm collectors have to register the owner of the samples collected and the exact place of collection, and facilitate the conditions for farmers to continuously cultivate the descendants of the populations conserved *ex situ*.

- Isozyme analysis has revealed significant genetic variability among and within populations of *Guizotia abyssinica*. Agromorphological traits analyses also revealed the potential for genetic variation. Isozyme variation for *Guizotia abyssinica* throughout Ethiopia has to be analyzed using large number of enzyme systems and large sample size to see the overall genetic diversity and genetic structure of this species in Ethiopia. This is very important to identify the macro and micro diversity centers of this species in the country. Modern molecular techniques such as Restriction Fragment Length polymorphism (RFLP), Randomly Amplified DNA Polymorphism (RAPD) and Amplified Fragment Length Polymorphism (AFLP) have to be applied to construct genetic maps of this species and to tag agronomic traits for high yield, nutritional qualities and to determine the position of resistance genes to various disease causing organisms and other environmental factors such as frost.

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10. APPENDICES

Appendix 1: -PGRC/E Code number, Accession number, Administrative Zone (according to current adminstirative, bounndaries), collecting site and of *ex situ* conserved populations of *G. abyssinica* (used for isozyme analysis)

Code number	Accession number	Administrative Zone	Site	Year of collection
1 (1E)	15040	South Welo	Kombolcha	1973
2 (2E)	15041	South Welo	Kombolcha	1973
3 (4E)	15181	Oromia	Bati	1976
4 (5E)	15189	Oromia	Kemissie	1976
5 (6E)	15595	South Welo	6.5 km from Dessie to Wegeltena junction	1979
6 (8E)	15766	North Shewa	18 km from Shewa Robit to Karakore	1981
7 (9E)	15767	North Shewa	42 Km from Shewa Robit to Karakore	1981
8 (10E)	15769	Oromia	5 Km from Kemissie to Denkeye Gelem	1981
9 (11E)	15770	Oromia	24 Km from kemissie to Bora	1981
10 (12E)	15771	South Welo	Fontenina (35 km from Kemissie to Kombolcha)	1981
11 (13E)	15772	South Welo	Chefa Mesendi (45 Km from Kemissie to Kombolcha)	1981
12 (14E)	15773	South Welo	Motikilo (17 Km from Kombolcha to Bati	1981
13 (16E)	15775	South Welo	25 Km from Kombolcha to Bati	1981
14 (17E)	15776	Oromia	Kersa (39 Km from Kombolcha to Bati	1981
15 (18E)	15783	South Welo	2 Km from town to Bistima	1981
16 (19E)	15784	South Welo	7 Km from Haik to Bistima	1981
17 (20E)	15785	South Welo	12 Km from Haik to Bistima	1981
18 (21E)	15787	South Welo	25 Km from Wuchalie to Haik	1981
19 (22E)	15788	South Welo	2 Km from Haik to Dessie	1981
20 (23E)	15790	South Welo	13 Km from Dessie to Kombolcha	1981
21 (24E)	15791	South Welo	16 Km from Dessie to Kombolcha	1981
22 (25E)	15804	South Welo	Dessie Zuria Cheffa village	1981
23 (27E)	202452	Oromia	4 Km from Cheffa Robi to Artuma	1982
24 (29E)	215682	South Welo	Abayimmer	1985

Appendix 2: -PGRC/E Code number, Administrative Zone, collecting site of *in situ* conserved populations of *G. abyssinica* (used for isozyme analyses)

Code number	Administrative Zone	Collecting sites
1 (1I)	South Welo	Kombolcha
2 (3I)	SouthWelo	Haik
3 (4I)	South Welo	Bati
4 (5I)	South Welo	Kemissie
5 (7I)	North Shewa	Estembuay
6 (8I)	North Shewa	18 km from Shewa Robit to Karakore
7 (9I)	North Shewa	42 Km from Shewa Robit to Karakore (near Senbete)
8 (12I)	South Welo	Fontenina (35 km from Kemissie to Kombolcha)
9 (13I)	Oromia	Chefa Mesendi (45 Km from Kemissie to Kombolcha)
10 (14I)	South Welo	Motikilo (17 Km from Kombolcha to Bati
11 (15I)	South Welo	Nechiro (10 Km Kombolcha to Bati)
12 (17I)	Oromia	Kersa (39 Km from Kombolcha to Bati
13 (19I)	South Welo	7 Km from Haik to Bistima
14 (22I)	South Welo	2 Km from Haik to Dessie
15 (23I)	South Welo	13 Km from Dessie to Kombolcha
16 (24I)	South Welo	16 Km from Dessie to Kombolcha
17 (26I)	Oromia	1 Km from Chefa Robi to Artuma
18 (27I)	Oromia	4 Km from Cheffa Robi to Artuma
19 (28I)	Oromia	13 Km from Chefa Robi to Artuma
20 (29I)	South Welo	Abayimmer

Appendix 3: -Frequency of occurrence of oil crops as intercrops in Sorghum fields and fields of other cereal crops, in different study sites.

No	Oil crops	Major oil crops	Study sites											
			Bati		Borkena Drainage		Haik		Layignaw Ataye		Merewa Adere		Shewa Robit	
			I	B	I	B	I	B	I	B	I	B	I	B
1	Noog	Sorghum	9	2	35	67	5	4	1	10	0	3	3	11
		Tef	0	2	7	26	2	72	5	13	0	6	1	22
		Others*	0	0	2	3	2	6	0	0	0	0	0	0
		Noog only	1		0		4		1		0		0	
2	Sesame	Sorghum	36	0	118	2	5	0	55	10	2	0	20	0
		Tef	0	0	0	0	1	0	1	1	3	0	85	0
		Others*	0	1	0	0	0	0	1	0	0	0	1	0
		Sesame only	4		0		0		0		0		0	
3	Linseed	Sorghum	1	0	7	0	0	3	1	2	0	0	0	0
		Tef	0	2	2	1	3	8	0	0	0	0	0	0
		Others*	0	0	0	0	0	0	0	0	0	0	0	0
		Linseed only	0		3		6		0		2		0	
4	Sunflower	Sorghum	4	2	4	2	0	0	2	1	0	0	0	0
		Tef	3	0	1	5	0	0	0	0	3	0	0	0
		Others*	1	1	1	0	0	0	3	0	0	0	0	0
		Sunflower only	0		0		3		0		0		0	
5	Safflower	Sorghum	8	6	0	0	0	0	0	0	0	0	5	0
		Tef	7	0	0	0	0	0	1	0	3	0	66	0
		Others*	0	0	0	0	0	0	0	0	0	0	0	0
		Safflower only	0		0		0		0		0		0	
6	Ethiopian mustard	Sorghum	15	0	24	0	11	0	8	1	3	0	9	0
		Tef	7	0	46	0	8	0	11	0	7	0	24	0
		Others*	0	0	5	0	0	0	0	0	0	0	2	0
		Ethiopian mustard only	0		0		2		0		0		0	

*- Finger Millet, Maize, Barley and Wheat considered together. I=intercrop, B=border crop.

Appendix 4: - Agromorphological traits characterized for Ethiopian mustard

Codes used	Name	Description	States
NCPP	Number of capsules per plant	-	-
CL	Capsule length	Measurement in centimeter	-
NSDPC	Number of seeds per capsule	-	-
NNPP	Number of nodes per plant	-	-
NPBPP	Number of primary branch per plant	-	-
PH	Plant height	Measurement in centimeter	-

Appendix 5: -Poems/Songs and sayings related to oil crops and Sorghum

No	Amharic (in English letter) '	Meaning	Implication	Common time to be used
1	Eshetun belten mirtun afesnew Alemduliahi shikur yidresew	We ate fresh green grains and collect our yield; thanks our God	Indicates multiple use values of sorghum starting from fresh green grains stage	During threshing sorghum
2	Bere zur bere zur Saywerewer Ye gena jenber Beriye minh kifu minh kifu Majet bigebu difdifu Dimiso Gomije wesedegn enkilifu	I drank Local beverage ("Tela") and ate "Dimiso", thanks for my oxen	Indicates the multi-purpose of sorghum both in beverages and food	During threshing sorghum
3	Dimiso beliche wuha tim mochalew Tiru metet honesh bitmechi wedalew	I ate "Dimiso" and became thirsty, and I will be too glad if you come being a nice beverage	The use of sorghum is not only used as food but also as beverages, which is as important as beautiful as beautiful lady	During weeding ceremonies and so on
4	Kegnazmach Bekolo Dubale balneber Ya kegilala Gorad aswesdogn neber	In the absence of maize and broad bean, we will be hungry because of late maturing nature of "Gorad"	Indicates the importance of mixed cropping of crops with different duration for maturity, for continuous supply of food for the family	Non-specific
5	"Ante tikur tekorkuara" sibal "minew bayehegn babebaye" ale alu noog	The seed of noog is black while its flower is very attractive and colorful	Indicates additional importance of noog decorating farmers' environment at its flowering stage	Fontenina (Borkena drainage)

Appendix 5 continued

6	Ye noog ye gomenzer ye selit ye telba Be Hidar wer derko regefe Abeba	November (Hidar) is the common month in which oil crops (noog, sesame, Ethiopian mustard, and linseed) is dried and ready to be harvested	Almost all edible oil crops are cultivated and harvested during the same season	Fontenina (Borkena drainage)
7	Ye noog ersha kerker new	Noog does not need intensive ploughing (land preparation), unlike other crops	Indicates the wide adaptation of noog to marginal and poor soils	Shewa Robit
8	Noog be sene Man yihon endene	Noog will grow well and give nice yield when sown in June (Sene)	Indicates the importance of planting time to get good yield	Shewa Robit
9	Mitishin ye selit wukiya yadirgew	Let's god make your labor (childbirth) as simple as sesame threshing	Indicates that dehiscent sesame varieties are simple to thresh	When mothers' give birth
10	Abebawu abebe beye noogu layi Engidih Yager lij mar enbelalen	It is time to eat honey, because noog is flowering	Indicates the importance of noog to produce noog by honey bees	During flowering stage of noog
11	Enkikit sibirbir ende noog ageda Meweld kifu new abro mebilat eda	Noog stem is easily broken down into pieces during threshing	Indicates the difficulty of separating noog from its byproduct by winnowing	During noog threshing
12	Minim biyarsu Endegomen aygorsu	Cultivate and eat safely and confidently	To indicate the key position of mustard in Ethiopian dishes	During the main rainy season
13	Be derek yarese na Be gomen ye gorese and new	Eating Injera with mustard and on time land preparation has equal satisfaction	Indicates the top position of mustard in Ethiopian dishes and the importance of on time land preparation	During the main rainy season and during land preparatio n

Appendix 6: - Selected IBPGR Descriptors of Noog

Codes used	Name	Description	States
NNP	number of nodes per plant	-	-
PH	Plant height (in centimeter)	-	-
NPB	Number of primary branch	-	-
NHP	Number of heads per plant	-	-
LL	Leaf length	Visual measurement taken at the middle part of the plant	1-very short, 3- intermediate 5-very long
LW	Leaf width	Visual measurement taken at the middle part of the plant	1-very narrow, 3- intermediate 5-very broad
AB	Angle of branching	Angle between stem and primary branch	1-very erect, 3-intermediate 5-90^{O} or more
HSZ	Head size	Visual measurement taken after ripening	1-very small, 3-intermediate 5-very big
STM CLR	Stem color	Visual measurement taken at the middle part of the plant at flowering stage	1-green 2-purple
FLR SZE	Flower size	Visual measurement taken at flowering stage	1-very small, 2-intermediate 5-very big
LF CLR	Leaf color	Visual measurement taken at the middle part of the plant after flowering	1-light green, 3- green 5-dark green
L MA	Leaf margin	Visual measurement taken at the middle part of the plant	1-small dented, 3- dented 5-roughly dented
LODG	Lodging	Lodging level taken at maturity	1-very little lodging, 5-some lodging, 9-extreme lodging
STM HR	Stem hairiness	Visual measurement taken at the middle part of the plant during flowering	1-less hairy, 3-intermediate 5-very hairy

Appendix 7: - Selected IBPGR Descriptors of Sesame

Codes used	Name	Description	States
PH	Plant height (in centimeter)	-	-
NCPA	Number of capsules per axil	-	-
NCPP	Number of capsules per plant	-	-
CL	Capsule length	Length in millimeter from shoulder to shoulder	-
NSPC	Number of seeds per capsule	-	-
NLPC	Number of locules per capsule	Number of chambers (locules) counted from a cross section of a capsule	-
NB	Number of branches per plant	Recorded after flowering	-
LODG	lodging	lodging level recorded before harvest	0-lodging, 1-very few, 5-almost 50% lodging, 9-complete lodging
STM CLR	Stem color	Color recorded at the middle of the plant after flowering	1-light green, 2-dark green, 3-green, 4-white grey,5-purple
STM SH	Stem shape	Stem shape in cross-section	1-square, 2-round
LF CLR	Leaf color	Presence or absence of pigment at the middle part of the plant after flowering	1-present 2-absent
BRH	Branching habit	Visual classification of plant type	1-non-branching 2-top branching 3-middle branching 4-basal branching
CAP SH	Capsule shape	Visual measurement at the middle part of the stem during flowering	1-tapered, 2-narrow oblong, 3-broad oblong 4-square
CAP CLR	Capsule color	Visual measurement when capsule is dry	1-white, 2-light brown, 3-brown, 4-reddish brown 5-grey 6- black
SHL THICK	Shell thickness	Physical measurement of hardness for mechanical harvest	3-thick7-thick
SD CLR	Seed color	Visual measurement taken after threshing	1-white, 2-light brown 3-brown, 4-reddish brown 5-grey, 6-black
DEHS	Dehiscence	Visual measurement when capsule is dry	1-dehiscence, 2-indehiscence

Appendix 8: - Selected IBPGR Descriptors of safflower

Codes used	Name	Description	States
AB	Angle of branching	The angle made between the branch and main axis	0- no branches, 3- appressed (15-20 ^{O}), intermediate (20-60^{O}), spreading (60-90^{O}), Dropping (90^{O}).
PH	Plant height	Height in centimeter	-
DPH	Diameter of primary head	Diameter of primary head (in mm) measured at the base.	-
CAPNO	Number of capitulum per plant	Number of heads per plant	
OLBS	Number of spines per outer involucral bract	-	0- none, 2- few, 5- intermediate, 7- many
OLBL	Outer involucral bract length	The spines on outer involucral bracts observed visually	-
OLBW	Outer involucral bract width	Outer involucral bract width in (mm) at the widest part	-
SDSZ	Seed size	Visual measurement	3- small, 5- intermediate, 7- large
INL	Internode length	The length measured between nodes	3- short. 5- intermediate, 7- long
OLB ATT	Outer involucral bract attitude	-	1- close, 2- open
SP LOC	Location of spines on Outer involucral bract	The distribution of spines on outer involucral bract	1- tip only, 2- tip and few apical, 3- tip and few basal, 4- tip and all along margins, 5- margins only
CAP SH	Capitulum shape	Primary head shape before flowering	1- conical, 2- oval, 3- flattened
GR H	Growth habit	The growth appearance observed visually	1- erect, 2- bushy
BR LOC	Branch locations	Location of branch son main axis	0- no branches, 1- predominantly basal, predominantly on the upper third of the plant, predominantly on the upper two-third of the plant
LF SH	Leaf shape	Shape of upper stem leaves	1- ovate, 2- oblong, 3- lancelet, 4- linear
LF MA	Leaf margins	-	1- entire, 2- serrate or dentate, deeply serrate
LF CLR	Leaf color	Visual measurement of leaf color	1- light green, 2- dark green, 3- greenish, 4- other
LF SP	Leaf spininess	Extent of leaf spinniness	0- non spiny, 3- few spines, 5- intermediate, 7- many spines
LF HR	Leaf hairiness	-	0- non-hairy, 5-few hairs, 5- intermediate 7-many hairs
BR EN	Bracts inclosing heads	How the head is enclosed by the bracts	1- incomplete, 2- complete

Appendix 9 : -Agromorphological traits characterized for sunflower

Codes used	Name	Description	States
AB	angle of branching	The angle made between the branch and main axis	0- no branches, 3- appressed (15-20 ^{O}), intermediate (20-60^{O}), spreading (60-90^{O}), Dropping (90^{O}).
BRL	Bract length	Measurement in centimeter	-
BRW	Bract width	Measurement in centimeter	-
DPH	Diameter to primary head	Measurement in centimeter	-
LFL	Leaf length	Measurement in centimeter	-
LW	Leaf width	Measurement in centimeter	-
NHPP	Number of heads per plant	-	-
NLPP	Number of leaves per plant	-	-
PH	Plant height	Measurement in centimeter	
SDSZ	Seed size	Visual measurement	3- small, 5- intermediate, 7- large

Appendix 10: - Selected IBPGR Descriptors of linseed

Codes used	Name	Description
NBB	number of basal branches	-
NUPB	Number of upper branch	
PH	Plant height	Plant height in centimeters
NBPP	Number of balls per plant	-
NSDPB	Number of seeds per plant	-

Appendix 11: - Questionnaire (Registered Interview) for ethnobotanical study of oil crops

Name of informant_____Age_____Sex_____Zone__Wereda _____Kebele_____

1a. Which edible oil crops are cultivated in your locality? b. Why do you cultivate them?

2a. Which of these species are cultivated in large scale? b. Why?

3a. Which of these oil crops are cultivated as companion crop of sorghum? b. Why?

DECLARATION

I, the undersigned, declare that this thesis is my own work and it has not been presented in other Universities, Collages or Institutions, seeking for similar degree or other purpose.

MULATU GELETA	18th of June, 2001	
NAME	DATE OF SUBMISSION	SIGNATURE